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Hydrologic Impacts from Potential Coal Strip Mining - Northern Cheyenne Reservation
Volume I

Northern Cheyenne Research Project
Lame Deer, MT

Prepared for

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This report presents the results of a large scale hydrologic study performed on the Northern Cheyenne Reservation. Data from surface water monitoring, groundwater monitoring, and geologic profiles is combined to estimate potential disruptions from future coal mine development on the reservation.

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VOLUME I

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory, Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methods that will meet these needs both efficiently and economically.

This report presents the results of an investigation designed to address questions raised by the Northern Cheyenne Indian Tribe concerning the potential impacts of coal strip mining on their Reservation in southeastern Montana. It serves as a technical and planning guide to the geology and water resources of the Reservation and correlates with other similar premining studies on the Northern Great Plains. The report also presents a method for assessment of impacts that will prove informative to the Northern Cheyenne Tribe and to a wide group of researchers, planners, and the general public interested in the problems related to energy development in the western United States. For further information, you may contact John F. Martin of the Energy Pollution Control Division in Cincinnati.

David G. Stephan
Director
Industrial Environmental Research Laboratory

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the results of an investigation designed to address questions of the Northern Cheyenne Indian Tribe concerning the potential impacts of coal strip mining on our Reservation in southeastern Montana. It serves as a technical and planning guide to the geology and water resources of the Reservation. The report also presents a method for mining impacts assessment that will prove informative to the Northern Cheyenne Tribe and to a wide group of researchers, planners, and the general public interested in the problems related to energy development in the western United States.

Allen Rowland

Allen Rowland, President
Northern Cheyenne Tribe
Lame Deer, Montana

ABSTRACT

This research project was initiated with the overall objective of assessing the possible impacts of coal strip mining to the groundwater and surface water resources of the Northern Cheyenne Indian Reservation.

Meteorological, groundwater and surface water monitoring networks were established to evaluate the occurrence, quantity, movement and quality of the region's water resources. Available geologic data were gathered, and field mapping and drilling programs were undertaken to delineate the near surface stratigraphy of the coal bearing Fort Union Formation. Three priority study sites containing strippable coal and representing varied hydrogeologic settings were selected for more detailed study.

Results of this project show the presence on the Reservation of a complete section of the Tongue River Member of the Fort Union Formation which contains eleven major coal seams. A stacked groundwater flow system exists in which extensive clinker deposits, thick coal seams, channel sandstones and unconsolidated alluvium in the major valleys store and transmit the major portion of groundwater. Water quality is variable and is principally the result of the aquifer mineralogy and the presence or absence of sulfur reducing bacteria. Hydrologic and salt balance calculations indicate that in the Tongue River along the Reservation, mean discharge increased by eight percent and dissolved solids load increased by six percent. In that part of Rosebud Creek located within the Reservation, mean discharge increased by 150 percent and the dissolved solids load increased by 39 percent. Postulated coal strip mining at three priority study sites in the Tongue River Valley, high central divide region and Rosebud Creek Valley would have impacts on the local surface water and groundwater resources. Water quality degradation from the leaching of spoils would affect the quality of the major streams. A large percentage of the leachable constituents in mine spoils would be removed by the first pore volume of spoil recharge and groundwater which passes through the spoil. Mining all strippable reserves of the Knoblock coal seam system along both sides of the Tongue River Valley from Birney Day Village to a point eight kilometers north of the town of Ashland would have a major impact on the regional groundwater quality and a significant impact on the quality of the Tongue River. Water quality impacts from coal strip mining would last for hundreds of years.

This report and a companion volume containing hydrologic data gathered from 1976 - 1979 were submitted in fulfillment of Grant Nos. R803556, R806082 and P00822801 by the Northern Cheyenne Research Project under the sponsorship of the U.S. Environmental Protection Agency and the Northern Cheyenne Tribe. This report covers the period from June 1, 1975 to May 31, 1978, and work was completed as of October 10, 1978.

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CHAPTER 1

INTRODUCTION

BACKGROUND

In a time of increasing national need for secure energy sources and the passage of air pollution laws, plans have been initiated to mine low sulfur coal and generate electric power in the northern great plains region. President Carter has set a goal to increase the Nation's 1977 coal production by 322 million metric tons (327 million short tons) before 1985. Approximately 35 percent of the United States coal reserve is contained in the near surface Tertiary Fort Union Formation and Wasatch Formation which lie in southeastern Montana, eastern Wyoming, and western North Dakota. It has been projected that to meet the President's goal, 60 new 4.5 million metric ton per year (5 million short ton per year), western coal field mines would be required. In addition to the strip mining of western coal, coal fired mine-mouth electrical generating plants have also been planned. One such plan, the North Central Power Study (BR, 1971), proposed 12 mine-mouth, coal fired generating plants for southeastern Montana alone which would produce 45,000 mW (Megawatts) of power, for primarily out-of-state users. Initially, such plans were criticized for over-projecting potential development. However, two 350 mW plants have already been built and two 778 mW plants are in the final permit stage. Strip coal mines have begun to utilize part of the estimated 36 billion metric tons (40 billion short tons) of strippable coal reserves in southeastern Montana.

Though such plans have been made and are being implemented, the social, economic, and environmental impacts of such actions have not been fully assessed. The impacts of energy development on the social-economic structure of an area, on the surface water resources and on the shallow groundwater, which is the principal source of domestic, municipal and stock water in the region, are of great importance to the residents and economy of the northern great plains.

One group that is concerned about the potential impacts energy development will bring to the region is the Northern Cheyenne Indian Tribe. They live on a 180,790 hectare (446,784 acre) reservation in southeastern Montana in the heart of the western coal field (Figure 1.1).

Today, 3,000 Northern Cheyenne with a per capita income of approximately $1,700 per year find themselves owners of 4.5 billion metric tons (5 billion short tons) of strippable low sulfur subbituminous coal and a total coal reserve of 45 billion metric tons (50 billion short tons). At the present time only a half hectare size pit, started in 1978, is being mined to provide coal to tribal members for home heating. However, in the 1960's and early

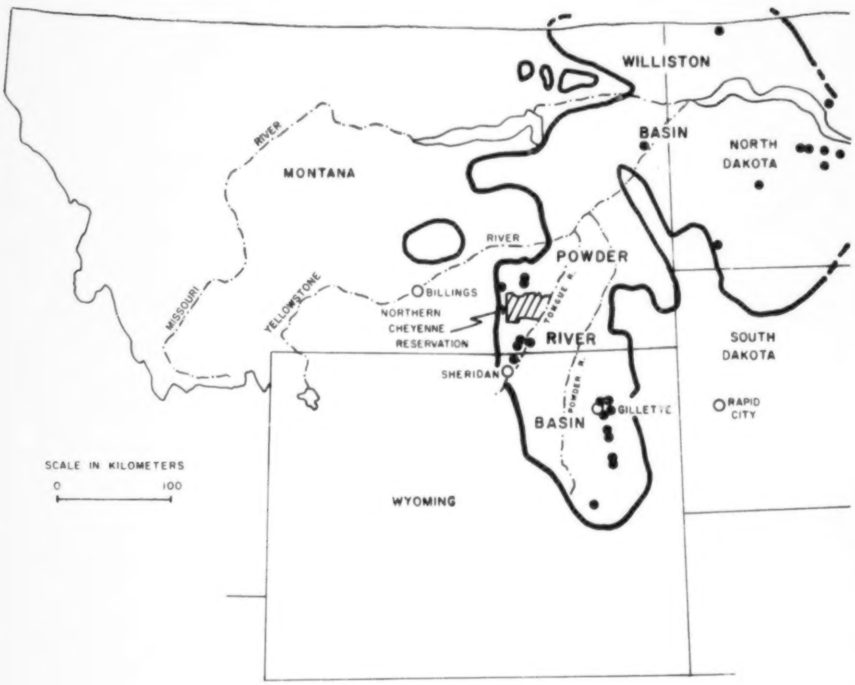
WILLISTON
BASIN
NORTH DAKOTA
MONTANA
RIVER
RIVER
MISSOURI
YELLOWSTONE
BILLINGS
NORTHERN CHEYENNE RESERVATION
POWDER
RIVER
BASIN
TONGUE R.
POWDER R.
SHERIDAN
GILLETTE
SOUTH DAKOTA
RAPID CITY
SCALE IN KILOMETERS
0
100
WYOMING

Figure 1.1. Location of Northern Cheyenne Reservation.

1970's, major energy companies had gained coal exploration permits with options to lease over 56 percent of the Reservation (Figure 1.2). In 1973, the Northern Cheyenne realized they had been encouraged to enter into these agreements by the Bureau of Indian Affairs (BIA) without knowing the extent and value of their coal resources or the impacts such large-scale development would have on the Reservation. During that year, the Tribe began legal actions to regain control of their land and resources, as well as provide time for needed resource inventories, impact analyses and management plan development. The Tribe was successful in preventing large-scale mining that would have started at that time. The Tribe began a tribal research group, the Northern Cheyenne Research Project (NCRP), that designed to seek funding and conduct research to assist the Tribe in planning for the future. In a response to the need to evaluate Reservation resources since 1973, the Tribe initiated research attempting to identify the existing human, social-economic, air, land, and water resources of their Reservation, and has delineated the possible potential impacts the tribe may face.

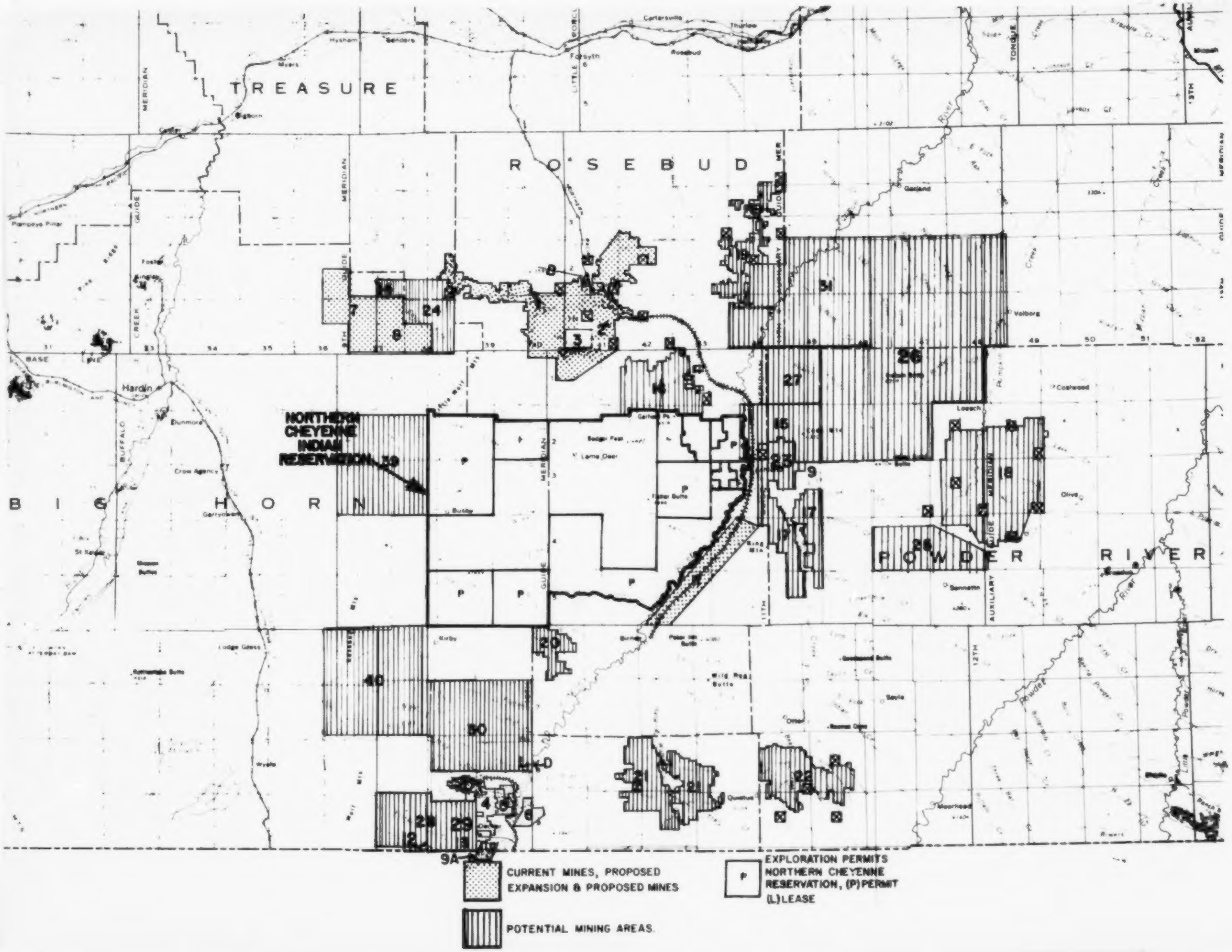
TREASURE
ROSEBUD
BIG HORN
POWDER RIVER
NORTHERN CHEYENNE INDIAN RESERVATION
Hardin
Crow Agency
Forsyth
Busby
Lame Deer
Ashland
CURRENT MINES, PROPOSED EXPANSION & PROPOSED MINES
POTENTIAL MINING AREAS.
EXPLORATION PERMITS NORTHERN CHEYENNE RESERVATION, (P) PERMIT (L) LEASE

Figure 1.2. Coal leases on the Northern Cheyenne Reservation and coal leases in the surrounding area. The leases are identified in Table 1.1.

TABLE 1.1. LEGEND FOR FIGURE 1.2

CURRENT MINES - PROPOSED EXPANSIONS

1. Western Energy: Mine Areas A, B, C, D, E, F.
2. Peabody Coal Co.: Big Sky Mine
3. Peabody Coal Co.: Proposed Lee Coulee Expansion
4. Decker Coal Co.: West
5. Decker Coal Co.: North
6. Decker Coal Co.: East
7. Westmoreland: Tract II
8. Westmoreland: Tract III
9. Coal Creek Mine
9A. Bighorn Mine

PROPOSED MINES

10. Nerco (PP&L): Spring Creek Mine
11. Montco-Peabody: Nance Mine
12. Shell Oil Co.: Pearl Mine
13. Consolidation Coal Co.: CX Ranch Mine

POTENTIAL MINE AREAS

14. Amax: Sarpy Creek
15. Montco: Cook Mountain
16. Greenleaf-Miller Creek: BLM Lease Study Area
17. Otter Creek Area: BLM Lease Study Area
18. Pumpkin Creek Area: BLM Lease Study Area
19. Seeney-Snyder Area: BLM Lease Study Area
20. Canyon Creek Area: BLM Lease Study Area
21. Hanging Woman Creek Area: BLM Lease Study Area: State Lands
22. West Moorhead Area: BLM Lease Study Area
23. Coalwood Ashland
24. Sarpy Creek
25. Stacy-Sonette
26. Foster Creek
27. Beaver Creek
28. Little Young's Creek
29. CX Ranch Expansion
30. Taylor Adsit
31. Lay Creek
32. Peabody Permit
33. Gulf Permit

RELATED POSSIBLE COAL ENERGY DEVELOPMENTS

A. Colstrip Units #3 and #4
B. Colstrip-Hot Springs Transmission Line
C. High Tongue Dam

PURPOSE AND SCOPE OF THE PROJECT

Five specific goals were set for the three-year project funded by the EPA:

1. Acquire the existing subsurface information presently housed in mineral company and governmental agency files;
2. Identify priority coal-development sites based on geologic and hydrogeologic analyses;
3. Evaluate the occurrence and movement of water on the Reservation and adjacent lands where necessary, with emphasis on the priority areas;
4. Determine the potential impacts of coal development to the hydrologic system of the Reservation;
5. Initiate a comprehensive water resources management plan that will aid in future resource use.

Basic resource inventory programs were initiated, and monitoring and mapping programs needed to provide information on the regional and local natural hydrologic and hydrogeologic systems of the area were developed and implemented.

A regional study such as this one is new to the coal-hydrology research concept in southeastern Montana. In the past, most impact research has been only mine site specific. Research has tended to emphasize local system impacts without evaluating how the work fits into the regional hydrology. Most research has dealt with only limited groundwater resource evaluation, and none has attempted to delineate hydrostratigraphic units within a region the size of this Reservation, which contains a complete section of the coal bearing Tongue River Member of the Fort Union Formation. The significance of clinker deposits within the local and regional hydrologic system has not been reported in any detail prior to this work. Impact analyses including pre-mining and post-mining groundwater surface water quantity and quality relationships are also presented.

In addition to regional analyses, emphasis was placed on three Priority Study Areas, each containing different mineable coal seams, and each situated in specific parts of the local and regional hydrologic systems. They were selected to represent typical potential mining sites on the Reservation and in the southeastern Montana region.

PREVIOUS REPORTS

All previous investigations of the geology and hydrology of the Northern Cheyenne Indian Reservation have been of reconnaissance value. Early geologic expeditions through the region described the general geology and reported on groundwater supplies and quality from limited sampling (Baker, 1928; Renick, 1929; Dobbin, 1929; Bass, 1932; Thom, et al., 1935; Perry, 1935). Geologic mapping of the eastern portions of the Reservation was attempted by Warren (1938 to

1939), but was not refined into a publication. The United States Geological Survey (USGS) began discharge measurements on the Tongue River in 1928; however, most of the other streams in the region were not instrumented until the 1960's and 1970's. The BIA hired consultants to conduct a water resource inventory for the Reservation in 1972; however, their work included primarily a review of the literature and estimates of runoff from Reservation watersheds (Hurlbut, Kersick, and McCullough (HKM) 1972, 1973, 1975). The USGS prepared two geohydrologic maps for part of southeastern Montana which included the Reservation area (Hopkins, 1973). Before the initiation of this project in 1975, there had been insufficient research on the geology, meteorology, surface water and groundwater resources of the area to attempt to predict the impacts coal development could have on the water resources. In 1977, special water quality studies were conducted and initial hydrologic analyses of the natural systems operating on the Reservation were performed as part of an EPA funded project (NCRP, 1977).

Pre-mining, mining, and post-mining impacts of coal strip mining to the water resources have been considered in environmental impact statements prepared for specific mines north and south of the Reservation (BIA, 1976; Van Voast, et al., 1974, 1975, 1976, 1977; Van Voast and Hedges, 1975; USGS, 1974, 1976; USGS and Montana Department of State Lands (MDSL), 1977). The Northern Cheyenne Tribe is currently not involved in large-scale mining. The methods of impact analyses and data on the pre-mining spoil hydrology presented by available off-Reservation studies were utilized in this report to evaluate the potential impacts mining on the Reservation would have on water resources.

PROJECT DEVELOPMENT

At the initiation of this research effort in 1975, all available data describing the natural geologic, meteorologic, groundwater and surface water systems operating in the Reservation area were collected and reviewed. It was concluded that existing basic data were inadequate to provide a foundation upon which meaningful mining impact analyses could be built. In an attempt to obtain necessary baseline information, meteorologic and hydrologic data collection networks were designed and implemented. Geologic mapping and field programs were initiated. Many of these programs are still continuing, for it is realized that initial programs have only provided sufficient information to establish system trends and further data needs. A long period of record is necessary to characterize more completely the natural systems of the Reservation which are believed typical of the western coal region.

Once adequate data were collected, interpretation and analyses of the information base were started. The types and extent of geologic formations found in the area were delineated. The coal stratigraphy and geomorphology of three areas with the potential for economical coal mining were described. Analyses of precipitation and evaporation records yielded a correlation with topography and a base for groundwater recharge evaluation and surface water system definition. Rock units which form the complex groundwater system operating within the Reservation were identified and hydrogeologic properties of coal, clinker, sandstone and alluvial material were described. Precipitation and surface water discharge records were correlated to define the surface water systems. Seepage run data were used to identify the contribution of groundwater to the surface water systems. Most of the project period was used to identify the existing natural system, since it is firmly believed that without careful delineation of the natural undisturbed or pre-mining systems, prediction of the coal strip mining impacts to the water resources would not be meaningful.

Intensive analyses of the potential impacts coal strip mining could have on the water resources of the Reservation was initiated in the last year of the project. After evalution of geologic and hydrologic data, general mine sites were selected in three areas. Pre-mining input/output models of the hydrologic system in the area were developed at each site. The emphasis of the mining impact section is on an evaluation of the post-mining water quality and quantity changes. Aquifer dewatering during mining and mine effluent quality impacts were recognized, but the absence of detailed mining plans and hydrogeologic data precluded detailed analyses. Post-mining impact analyses included laboratory saturation extract testing of drill cuttings, and leaching tests of representative samples for each mine. Inputs to spoil hydrology modeling were obtained from available literature. Impact analyses techniques were evaluated and the use of these methods for regional, large-scale coal development impact prediction was discussed. A brief discussion of management possibilities of the Tribe's water resources in light of potential impacts from mining on the Reservation and from regional mining was prepared.

CHAPTER 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

GEOLOGY

Approximately 90 percent of the Reservation surface lies in the coal bearing Tongue River Member of the Paleocene Fort Union Formation. The Member, where complete, is about 500 m (1640 ft) thick.

Fine-grained clastics and coals dominate the Tongue River Member. Nearly all sediment is medium to fine grained sandstone, siltstone, or shale. Shale is often found near the tops and bases of coal seams. Channel sands are common. Thin limy zones are often present.

Eleven major coal bed systems have been identified on the Reservation. From highest to lowest stratigraphic level, they are the Roland, Smith, Anderson, Canyon, Cook, Wall, Pawnee, Sawyer-Knobloch-Lee-Nance, Rosebud-McKay, Flowers-Goodale, and Robinson.

Alluvium up to 37 m (120 ft) thick in places fills the valleys of Rosebud Creek, Tongue River, and their tributaries.

Clinker beds, formed by the burning of major coal seams, cover about one-third of the Reservation surface and reach thicknesses of up to 70 m (230 ft). The most extensive clinker beds are those related to the Anderson and Knobloch coal seams.

Individual coal seams are continuous over much of the Reservation, but may split, pinch out, or merge with other seams. Interburden units of shale, siltstone and sandstone are, for the most part, fairly discontinuous.

The Eocene Wasatch Formation caps highland areas in the south-central part of the Reservation.

Strata are nearly flat lying with a general dip of less than one degree to the southeast.

Minor northwest-southeast and northeast-southwest trending faults and joints occur. Measured vertical displacement so far has been limited to 50 m (160 ft) or less.

Present-day Reservation topography has been formed by rivers dissecting an ancient plateau surface.

GROUNDWATER

Alluvium, clinker, sandstone and coal are the major near-surface aquifer lithologies on the Reservation.

Four hydrogeoligc units, the Unconsolidated, Anderson, Knobloch, and Lower Tongue River, have been identified. These units store and transmit groundwater in the near surface hydrogeologic system.

Clinker deposits are major components of the identified flow systems. The fractured nature of these deposits result in a range of hydraulic conductivities and recharge potentials.

The hydraulic properties of clinker are dependent on the thickness of the coal burned and on the quantity of coal clinker produced.

In the water years 1975 and 1976, recharge was greatest to the unconsolidated deposits in the major stream valleys and clinker deposits. Recharge to the confined system was negligible.

Hydraulic conductivities estimated for coal aquifers fall within the range of those reported in the literature.

Groundwater quality relationships are influenced by sulfur reducing bacteria in deeper flow systems and by ion exchange.

The principal constituents of the groundwater are sulfate, calcium, and bicarbonate ions. The presence of calcium and magnesium usually is interpreted to indicate recharge is entering the system.

The Tongue River receives groundwater discharge from bedrock and alluvial aquifers along the reach of the Reservation.

Rosebud Creek receives groundwater discharge along the reach within the Reservation, although rates are small.

SURFACE WATER

The Tongue River derives its principal hydrologic and water quality characteristics in the upper reaches above the Tongue River Dam. Snowmelt from the Big Horn Mountains, irrigation in Wyoming, and streamflow regulation by the Tongue River Reservoir are dominating influences on the annual hydrograph and salinity trends of the Tongue River in Montana.

Groundwater discharge is a small component of the total discharge of the Tongue River below the Tongue River Dam, comprising about 16 percent of the streamflow at the northern boundary during baseflow periods. The mean groundwater seepage rate to the Tongue River along the Reservation was found to be 0.01 cubic meters per second per river kilometer (0.55 ft^3/sec/r mi) during the fall and winter base flow periods measured.

The mean discharge between Tongue River gaging stations at either Reservation boundary increased by 1.13 m^3/sec (39.9 ft^3/sec), or about eight percent during the study period. The river was found to gain an average of 0.798 m^3/sec (28.2 ft^3/sec) from groundwater discharges and 0.402 m^3/sec (14.2 ft^3/sec) from surface water discharges. Consumptive uses from irrigation caused an average annual rate of depletion of 0.095 m^3/sec (3.36 ft^3/sec). Evaporation losses were calculated to occur at a mean annual rate of 0.071 m^3/sec (2.51 ft^3/sec).

Rosebud Creek is a prairie stream that derives its principal characteristics from seasonal climatic patterns, topographic controls, and geologic deposits bordering the creek or its tributaries. Rosebud Creek was found to gain flow throughout its upper half, and lose flow throughout its lower half, on an annual basis.

Groundwater discharge to Rosebud Creek comprises about 23 percent of the total discharge at the northern Reservation boundary during baseflow periods. The mean groundwater seepage rate to Rosebud Creek on the Reservation was found to be 0.001 m^3/sec/r km (0.08 ft^3/sec/r/mi) during the fall-winter baseflow periods measured.

The mean discharge between Rosebud Creek gaging stations at either Reservation boundary increased by 0.653 m^3/sec (23.1 ft^3/sec) or about 150 percent during the study period. The creek gained an average of 0.137 m^3/sec (4.84 ft^3/sec) from groundwater discharge and 0.414 m^3/sec (14.6 ft^3/sec) from surface tributary discharge. Evaporation losses were calculated to occur at a mean annual rate of 0.033 m^3/sec (1.17 ft^3/sec).

The Tongue River at the state line has already picked up 81 percent of the average dissolved solids concentration measured at Miles City, Montana, primarily due to the effects of irrigation return flows in Wyoming. The average dissolved solids concentration increased by 38 mg/l or eight percent between the two NCRP sampling stations at the Reservation boundaries.

Most surface waters on the Reservation are a calcium-magnesium-bicarbonate type normally associated with streams receiving most of their water from lower-salinity sources such as snowmelt, storm runoff or clinker-alluvial aquifers. Cook Creek and Muddy Creek have a calcium-magnesium sulfate-bicarbonate water type higher in salinity due to pronounced effects of groundwater and spring flow from coal and sandstone aquifers in the upper part of the drainages above the clinker zones.

Total dissolved solids at NCRP sampling stations on the Tongue River cycled between lows of 200 mg/l to highs of 700 mg/l during water years 1976 and 1977.

Rosebud Creek at the northern Reservation boundary has already picked up 85 percent of the average dissolved solids concentration measured at the mouth of Rosebud Creek. The average dissolved solids concentration increased by 203 mg/l or 37 percent between the two NCRP sampling stations at the Reservation boundaries.

Dissolved solids concentrations in Rosebud Creek were usually higher but less variable at either sampling station than in the Tongue River. The sampled range at RBC #2 was from 400 to 650 mg/l and was 550 to 900 mg/l at RBC #1. The principal reason for the lack of salinity variation is due to the dominance of discharge from clinker and alluvial aquifers directly to the creek and its tributaries, and lack of irrigation.

A hydrologic balance equation was applied to NCRP Tongue River and Rosebud Creek data. The calculated downstream discharge at TR #1 was 0.7 percent less than the measured value. The calculated discharge at RBC #1 was 9.2 percent less than the measured discharge.

A salt balance equation was applied to NCRP water quality data once the hydrologic system was balanced. The calculated dissolved solids concentration at TR #1 was nine percent higher than the measured value and the calculated value at RBC #1 was two percent lower than the measured value.

IMPACTS

Pre-mining exploration and mine plan drilling may impact the natural groundwater systems.

During mining, reduction of water levels in wells, destruction of wells, and the reduction or disappearance of spring flow are the major impacts. Water quality impacts from a nitrate rich mine effluent can occur.

Post-mining spoil water is higher in total dissolved solids than the natural pre-mining groundwater.

Quantification of recharge rates of the spoil, and the quantity and quality of resulting leachate entering the groundwater flow system, is necessary to predict post-mining impacts to the water resources.

Single 4.9 to 9.8 million metric tons per year (5 to 10 million short tons per year) mines have a local impact on the quantity and quality of the adjacent surface water and groundwater system. Salinity impacts to the Tongue River and Rosebud Creek are expected to be minimal.

Extensive mining of the Tongue River Valley will impact the groundwater and surface water systems operating in the region. Groundwater with higher TDS, and chemical constitutent concentrations will be unusable for irrigation and mine site vegetation use. Downgradient from the mine site, water quality will gradually improve; however, high sodium adsorption ratio (SAR) and TDS values may limit the use of the water. Total dissolved solids in the Tongue River would increase from 16 mg/l during mean flows to over 500 mg/l during very low flow periods depending on the rate of recharge to the spoils.

The majority of leachable material is removed from the overburden samples by the time one pore volume of water passes through the sample.

Both groundwater and spoil water will leach constituents from mine spoils. Local groundwater used in tests leached chemical constituents from the overburden sample.

The time required to pass one pore volume of water through spoil material at the three postulated mine sites ranged from a low of 100 years at the Indian Coulee mine site to a high of 1,500 years at the Buffalo Jump mine site.

The length of time mining impacts could affect the regional water resources is measured in hundreds of years.

RECOMMENDATIONS FOR FUTURE RESEARCH

GEOLOGY

The structure of coal clinker beds needs more intensive study in order to determine which zones within the clinker are the main transmitters of water.

An extensive drilling and geophysical logging program on the unexplored portions of the Reservation is needed in order to define stratigraphic correlations between coal seams and to define possible additional reserves of strippable coal.

Major massive sandstone bodies on the Reservation need more thorough surface mapping and subsurface confirmation with drill logs, in order to determine their configuration.

HYDROLOGY

Additional studies of the flow systems operating on the Reservation, especially the identification of recharge areas of the deeper flow systems operating in the Tongue River Member, are needed. A series of deep wells should be drilled in the suspected highland recharge area and its flanks, to measure head differences, recharge rates, and water quality changes with depth.

Detailed pump testing of representative wells in the coal, clinker sandstone and alluvial aquifers is needed to refine hydraulic conductivity calculations. Special attention should be given to documenting the hydraulic conductivities of clinker, as this is an important hydrogeologic unit, adjacent and downgradient from most proposed mining operations in the region.

An array of two or more wells finished in alluvium, clinker, and bedrock material, ideally located adjacent to existing stream gaging stations, should be instrumented with continuous water level recorders for one or more years. Comparisons of stream stage hydrographs with well hydrographs would indicate trends in groundwater recharge, discharge and storage in relation to fluctuations in river stage and discharge. Such data would greatly assist interpretation of seepage run results and groundwater discharge rates to the Tongue River and Rosebud Creek.

Water occurance, water storage, and use by plants in the unsaturated zone, is a significant component of the hydrologic balance. Field studies using lysimeters or other soil moisture indicators should be conducted in conjunction with concurrent precipitation and well measuring programs.

IMPACTS

Monitoring of groundwater levels should continue to refine estimates of recharge to the various aquifers. Accurate data on the rates of recharge for clinker are critical for determining the impact post-mine waters would have on the adjacent water resources.

Additional seepage runs should be conducted on Rosebud Creek and on Tongue River to refine groundwater discharge rates. These data are very useful for checking the hydraulic conductivities of alluvium and for predicting the influence mining will have on surface water resources.

The impact of pre-mining drilling operations on the natural groundwater system should be studied.

Spoil hydrology research is at an early stage. Accurate predictions of the impacts of a mining operation to the quality and quantity of the associated hydrologic system cannot be performed without representative values of spoil water chemistry, spoil hydraulic properties and recharge rates. Therefore, mining impact research in the immediate future should focus on spoil hydrology.

RECOMMENDATIONS FOR WATER RESOURCES MANAGEMENT

The Northern Cheyenne Tribe may wish to consider becoming more involved in federal or interstate water agreements to protect its interest in the Tongue River. Water use activities in Wyoming greatly influence the quantity and quality of tribal water supplies from the Tongue River. Any additional use of water in Wyoming will result in higher TDS concentrations in the Tongue River in Montana. Agreements regarding the acceptable limits of TDS in the Tongue River as it enters Montana will help ensure a water supply of adequate quality as well as quantity.

There is a need to develop a predictive capability to assess the cumulative water quality impacts of energy, agriculture, and domestic projects on the Tongue River. No procedures are currently available to assess the water quality impacts of planned energy developments in the basin. Site specific environmental impact statements only address impacts from a single proposed development. Potentially affected parties, such as the Tribe, federal and state agencies, and private firms, have no means to determine how the impacts of any single proposed development relate to water impacts from other developments. In the Tongue River Basin alone, current proposals include three coal strip mines and one major power plant in Wyoming and eight new or expanded coal strip mines in Montana. Additional irrigation studies are also being conducted in Wyoming and Montana.

It is recommended that a hydrologic and water quality systems model of the Tongue River in Montana and Wyoming be developed to study and critique the cumulative effects of numerous site specific environmental impacts. Such a model could be developed using existing information from the USGS, Montana State Water Planning model, the Tetratech water quality model for the Tongue River and other public and private sources. The model should be capable of handling diverse water quality effects of mining, agriculture, energy production, and domestic uses. It should also be understood and used by the public and special water use groups.

Leadership and possible funding for development of a model is contained in the designated 208 water quality management agencies in Montana and Wyoming, and programs under the Surface Mining Control and Reclamation Act of 1977. It is imperative that all affected political jurisdictions - federal, state, and tribal - be involved in developing a workable planning tool that can be used by all parties.

The results of this study indicate that coal strip mining in local groundwater recharge areas, such as the Buffalo Jump area, have the most potential for adverse salinity impacts on Reservation water resources. The hypothetical mine modeled in that area caused significant degradation of water quality in springs and small streams that receive groundwater discharging from resaturated mine spoils. Mining in locations which are neither active groundwater recharge nor discharge areas, such as the hypothetical Logging Creek or Indian Coulee mine areas, have relatively minor impacts on Reservation water resources. It must be emphasized that while this study indicates that salinity impacts from potential mines in the Logging Creek or Indian Coulee areas do not appear great, the low level effects on water quality that would occur would not become evident until 50 years or more following mining, and would continue for hundreds of years in the future. The protracted time element in water quality impacts from coal surface mining parallels that of nuclear waste disposal. Appropriate management techniques for such long term impacts have not been developed or tested. Other water quality impacts from mining, such as sediment or heavy metals pollution, may be of more concern than salinity in certain cases.

Results of this study demonstrate how valuable it is to understand as much as possible about the actual hydrologic and geologic systems of a region such as the Northern Cheyenne Reservation, in order to evaluate general coal strip mining impacts. This study was conducted in response to the unique position taken by the Northern Cheyenne Tribe in the early 1970's. The Tribe demanded information on the potential impacts to the water resources of the Reservation before the decision was ever made to start mining its coal reserves. Since no specific mining venture was proposed, the research objectives called for a regional analysis of Reservation geology, groundwater and surface water occurrence and movement, and water quality relationships.

The regional research aspects of this study yielded data on the cause and effect relationships between geology, groundwater, and surface water that have not been heretofore assembled in a single report. Because of the Reservation's location and topography, information on most of the coal bearing Tongue River Member of the Fort Union Formation was collected and analyzed. Adequate understanding of the larger hydrologic systems operating in an area was found to be essential before the water quality impacts of any potential mine could be evaluated. The systems approach employed in this investigation pointed out key areas requiring further research, such as the importance of groundwater recharge to clinker and alluvial aquifers, groundwater quality changes that occur as water moves downgradient in coal seam-clinker aquifers and the amount of potential recharge to mine spoils.

It is recommended that federal, state, and tribal resource managers attempt to develop an understanding of the natural hydrologic systems on a regional scale prior to conducting intensive site specific mining impact assessments. In this manner, the relative magnitude and relationships of water related impacts from one mine to other proposed developments can be more fully understood and can improve over-all water resources management planning.

CHAPTER 3

GEOGRAPHY

INTRODUCTION

The focus of this project is the Northern Cheyenne Indian Reservation, located about 160 kilometers (100 miles) east of Billings, Montana, and 130 kilometers (80 miles) north of Sheridan, Wyoming (Figure 1.1). Southeastern Montana is a part of the northern great plains. The countryside is generally rolling grasslands with scattered to heavy stands of ponderosa pine. The land surface ranges in elevations from 610 to 1,646 m (2,000 to 5,400 ft) above MSL (mean sea level). The major streams in the area, the Bighorn, Little Bighorn, Rosebud Creek, and the Tongue River, all flow to the north and are tributary to the Yellowstone River which flows to the east through Forsyth, Montana. The Yellowstone flows into the Missouri southwest of Williston, North Dakota. The region is generally rural with about one person per square mile. The agricultural economy specializes in beef production.

Coal strip mining occurs on a large scale at several locations in southeastern Montana. Two of the most active areas are at Colstrip, 21 km (13 mi) north of the Northern Cheyenne Reservation, and at Decker, 29 km (18 mi) south of the Reservation. Mining is also conducted northwest of the Reservation at the Absoloka or Sarpy Creek Mine. A mine is planned by MONTCO adjacent to the Tongue River, near Birney Day Village, to commence shipping coal in 1984.

RESERVATION GEOGRAPHY

The Northern Cheyenne Indian Reservation includes an area of 180,790 hectares (446,784 acres). Most of this area was initially reserved by the federal government for the Tribe in 1884. The Reservation area is principally a dissected upland with rolling grasslands and timber stands of ponderosa pine. The land surface has pronounced relief. The altitudes range from 1,461 m (4,792 ft) above MSL at Crazy Horse Butte southwest of Busby, Montana to about 870 m (2,850 ft) above MSL in the Tongue River Valley at the northern boundary. The central portion of the Reservation is an upland plateau which rises approximately 300 m (1,000 ft) above the adjacent country. This upland has been deeply dissected by the Tongue River, Rosebud Creek and their tributaries (Figure 3.1).

All drainages on the Reservation are enclosed in the Yellowstone River

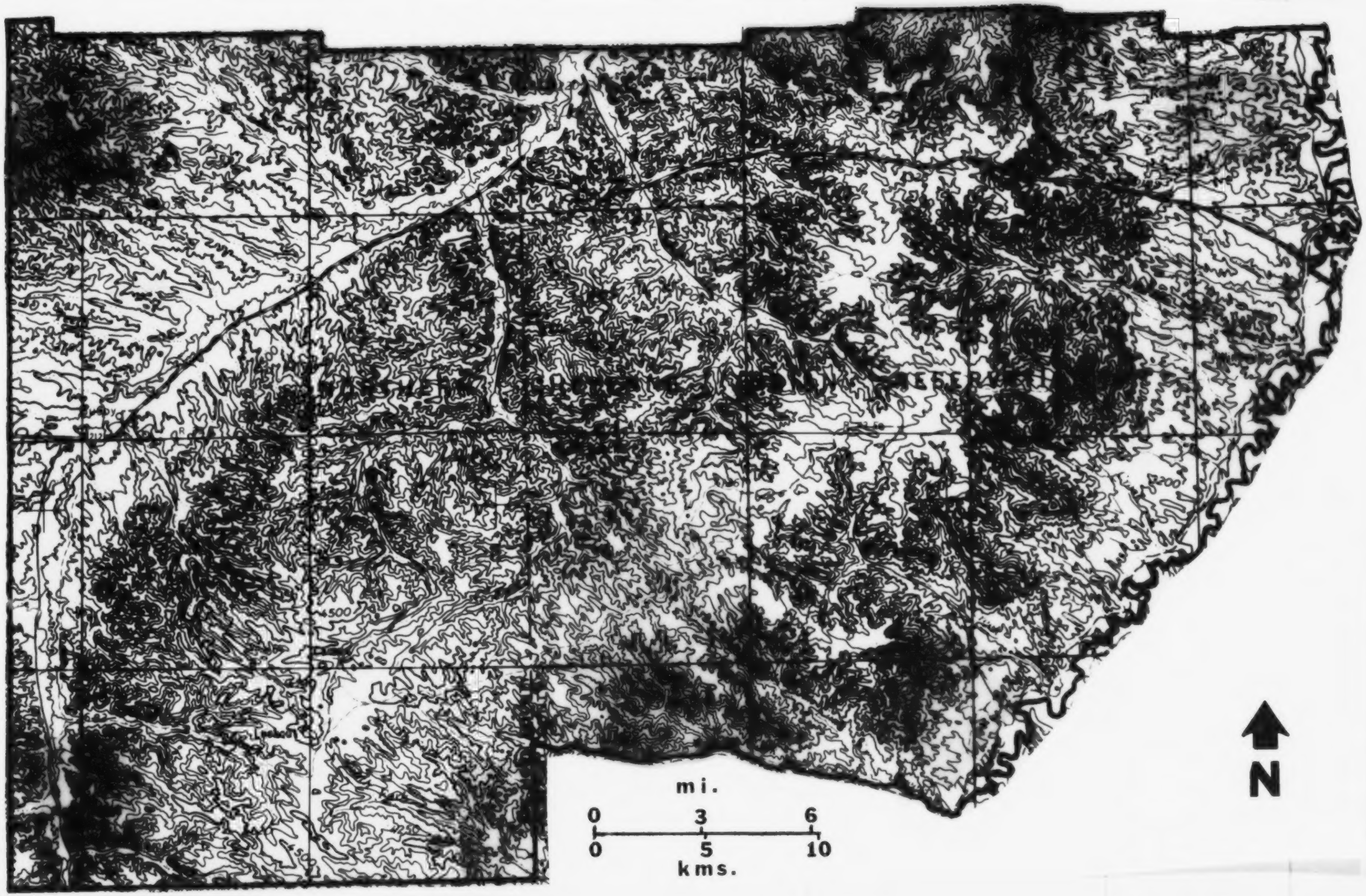
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Figure 3.1 Topography of Northern Cheyenne Reservation.

Basin. Drainage is generally northeastward, via Rosebud Creek flowing near the western boundary and through the north central portion of the area, and via the Tongue River, forming the eastern boundary.

The principal towns in the area are Lame Deer, the seat of the Tribal Government, Busby to the west, Birney Village to the south, and Ashland just east of the Reservation (Figure 3.2). The Northern Cheyenne population residing on or adjacent to the Reservation numbers 2,673. Unlike many reservations which have been subjected to non-Indian homesteading, 99 percent of the Northern Cheyenne Reservation remains in trust under Tribal or alloted ownership.

The main industries on the Reservation are agriculture: cattle and timber production primarily (Figure 3.2). The population density of the Reservation is four times (4.4 persons per square mile) that of southeastern Montana. Agriculture and forestry can support only a small portion of the total reservation population. Various tribal programs, public schools and government agencies employ the largest percentage of the work force. Private construction, retail and service businesses also provide some employment. However, the total number of available jobs does not fully support the population.

Unemployment rates are 40-60% depending on the season. The per capita income is only $1,613, about one-fourth of the national average (Nordstrom et al). Relatively few Northern Cheyennes have benefitted from steady employment in energy development industries.

In the winter of 1977 through 1978, the Tribe opened the Midway Coal Mine, a small half hectare size pit. The mine produced less than 980 metric tons (1,000 short tons) of coal. All production was for local tribal use. No other mines are in operation on the Reservation.

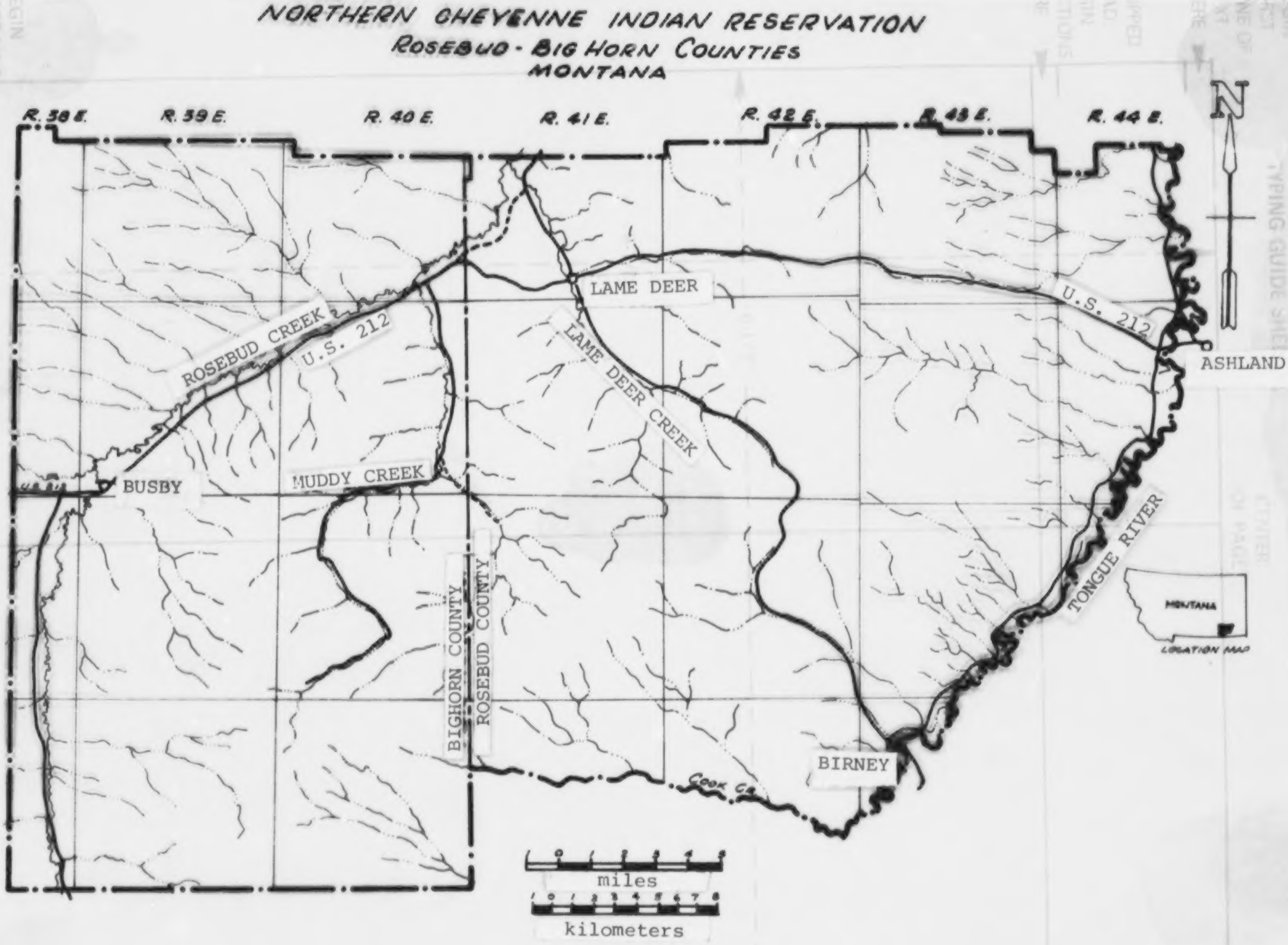

NORTHERN CHEYENNE INDIAN RESERVATION
ROSEBUD - BIG HORN COUNTIES
MONTANA
R. 38 E.
R. 39 E.
R. 40 E.
R. 41 E.
R. 42 E.
R. 43 E.
R. 44 E.
T 2 S
T 3 S
T 4 S
T 5 S
N
LAME DEER
U.S. 212
ASHLAND
ROSEBUD CREEK
U.S. 212
LAME DEER CREEK
BUSBY
MUDDY CREEK
TONGUE RIVER
MONTANA
LOCATION MAP
BIGHORN COUNTY
ROSEBUD COUNTY
BIRNEY
COOK CR.
0 1 2 3 4 5
miles
1 0 1 2 3 4 5 6 7 8
kilometers

Figure 3.2. The Northern Cheyenne Indian Reservation.

CHAPTER 4

METEOROLOGY

INTRODUCTION

The definition of the region's climate is essential for delineating the natural hydrologic system of that area, and necessary for the prediction of potential impacts to that system from coal strip mining. Analyses of regional and Reservation precipitation and evaporation patterns were the principal focus of the meteorological data collection program.

The climate of the region is continental and semi-arid. Regional distribution of precipitation is influenced by large mountain ranges to the south and west and by variations in topography. Analyses of precipitation patterns on the Reservation show the greatest amount falls in the western portion and central highland. The smallest amount is in the Tongue River Valley to the east. Review of historical data from the Busby, Lame Deer, and Colstrip stations showed that the project period was a period of slightly above average precipitation.

PREVIOUS WORK

Basic climatological data for the region was obtained from the Natioanl Oceanic and Atmospheric Administration Climatalogical Data Reports for Montana and Wyoming (NOAA, 1930 to 1978). General regional descriptions of the climate and site specific analyses of the meteorological station data associated with proposed mines in the region have been conducted as part of environmental impact statements for the Westmoreland and Decker mines (BIA, 1976; USGS and ADSL, 1977). Regional isohyetal maps have also been prepared for the area by the Montana Department of Highways (MDH) from data organized by the U.S. Soil Conservation Service (MDH, 1976).

METHODS

Climatalogical data collection has included the establishment of four continously recording precipitation weighing gages in the winter of 1976, two Class A evaporation pans in mid-summer 1976 and the manning of the Lame Deer NOAA station since April, 1978 (Figure 4.1). Records from surrounding NOAA Stations were analysed to characterize the distribution of precipitation in the region. Regional evaporation data were also reviewed.

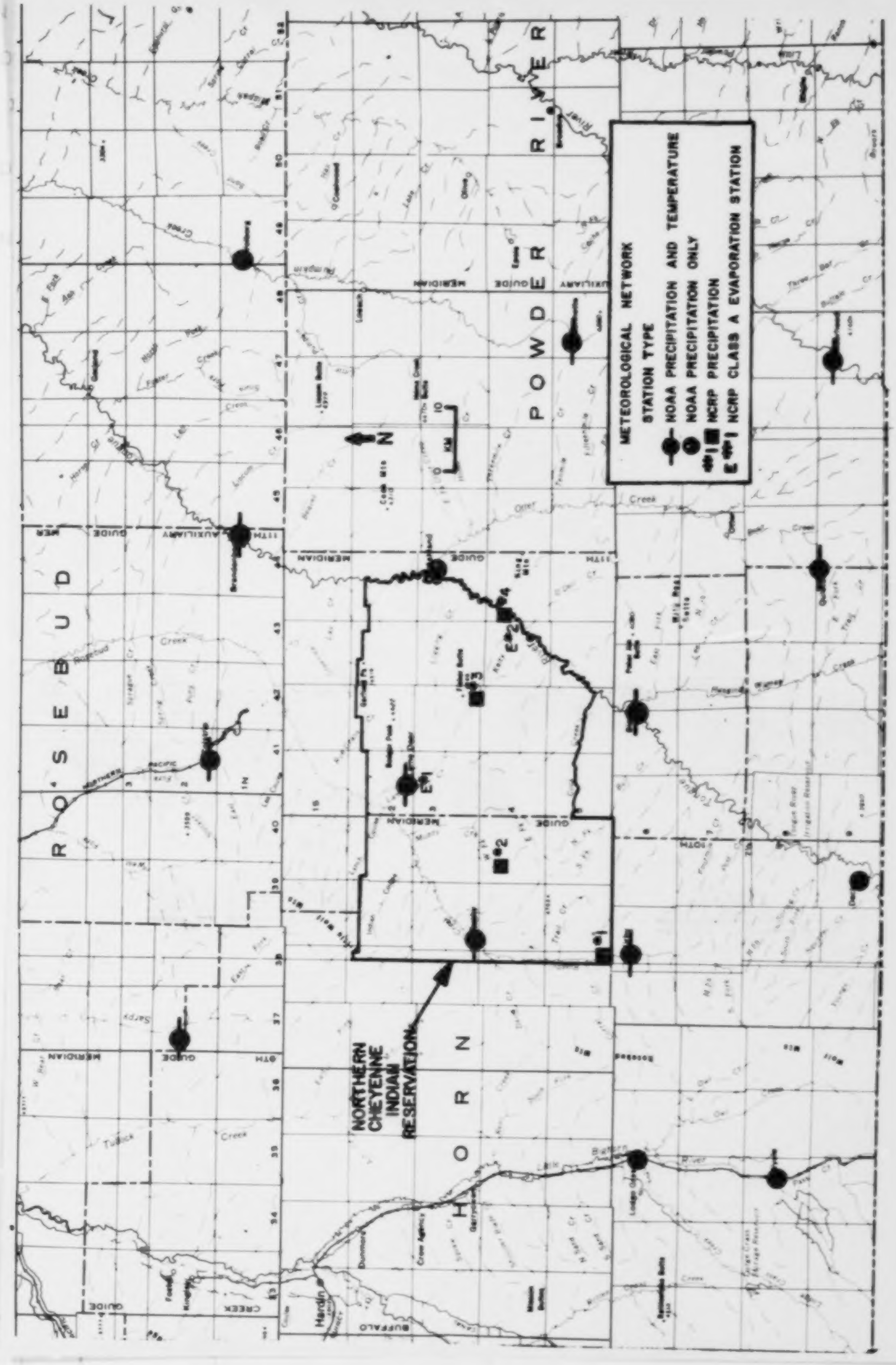

METEOROLOGICAL NETWORK
STATION TYPE
NOAA PRECIPITATION AND TEMPERATURE
NOAA PRECIPITATION ONLY
NCRP PRECIPITATION
NCRP CLASS A EVAPORATION STATION
ROSEBUD
POWDER RIVER
HORN
NORTHERN CHEYENNE INDIAN RESERVATION
N
KM
10
Hardin
E1
E2
2
3
4

Figure 4.1. Location of meteorologic stations.

REGIONAL SETTING

The climate of southeastern Montana is continental and semi-arid and is characterized by abundant sunshine, low relative humidity, moderate wind movement, light precipitation, and wide daily and seasonal temperature variations. The winters are moderately severe with cold waves occurring every winter, but varying in intensity. Temperatures rarely exceed 38°C (100°F) in the summer or fall below -40°C (-40°F) in the winter. Local differences in the regional climate are results of changes in relief, slope and aspect, humidity, plant cover, and man's activities.

The Bighorn Mountains to the southwest and mountain ranges of the Rockies to the west have significant influence on the precipitation, temperature and wind patterns in southeastern Montana. Maritime Pacific air masses predominate during the summer months. The alternate cooling and warming of these air masses as they cross the state removes much of their moisture prior to reaching the area. Cold arctic air masses, which move southward along the eastern front of the Rockies, predominate during the winter. Most of the precipitation which occurs in the region occurs in early spring and summer when moisture-laden continental tropical air moving northward is progressively cooled (USGS and MDSL, 1977).

Figure 4.1 indicates the location of NOAA established stations in the region surrounding the Reservation. The annual distribution of precipitation in southeastern Montana is shown in Figure 4.2. Generally, the area receives an average of 30 to 43 centimeters (cm) (11.8 to 17.0 inches (in)) of precipitation per year. Precipitation is highest in the topographically higher plateau regions and lowest in the lower valley areas. The annual NOAA precipitation data at Busby, Lame Deer, and Colstrip were plotted for the period of record and are presented in Figure 4.3. Analyses of these data indicate that the 1975-1978 study period was a slightly wetter period than average. Other wet periods were the early 1910's and 1940's. Drier periods occurred in the late 1910's, early 1930's, and early 1960's.

Regional evaporation data were estimated from maps in Linsley, et al (1949) which showed normal annual evaporation from Class A pans on the Northern Cheyenne Reservation is about 139 cm (55 in) per year. Approximately 70 to 80 percent of the total annual evaporation occurs from May to October.

Class A pans data for southeastern Montana at Huntley, Montana near Billings, and the Sarpy Creek Westmoreland mine just northwest of the Reservation showed a total water loss of 87.68 cm (34.52in) and 80.52 cm (31.7 in) in 1975 respectevely (NOAA, 1975; BIA, 1977). Analyses of corrected evaporation data indicated that net evaporation loss after adjustment for precipitation would be about 50.8 cm (20 in) per year. Work done in the Otter Creek area to the east of the Reservation showed that the growing season for natural grassess begins in April and ends in the middle of July when available soil moisture is consumed (BLM, 1975).

RESERVATION SETTING

The Reservation area is topographically higher than most of the surrounding

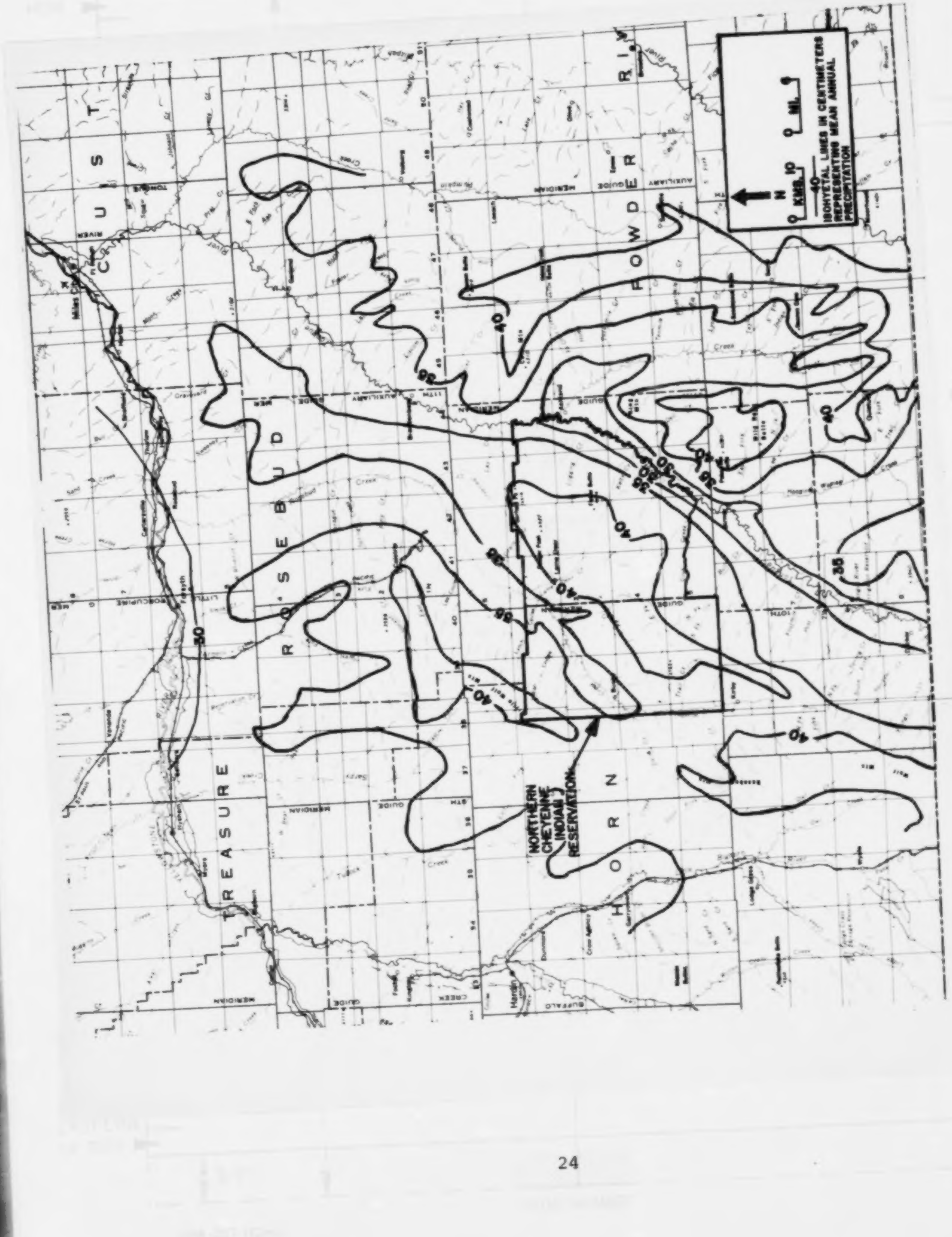

CUSTER
ROSEBUD
TREASURE
POWDER RIVER
BIG HORN
NORTHERN CHEYENNE INDIAN RESERVATION
30
35
40
N
0 KMS. 10
0 MI. 5
40
ISOHYETAL LINES IN CENTIMETERS REPRESENTING MEAN ANNUAL PRECIPITATION

Figure 4.2. Isohyetal map of southeastern Montana.

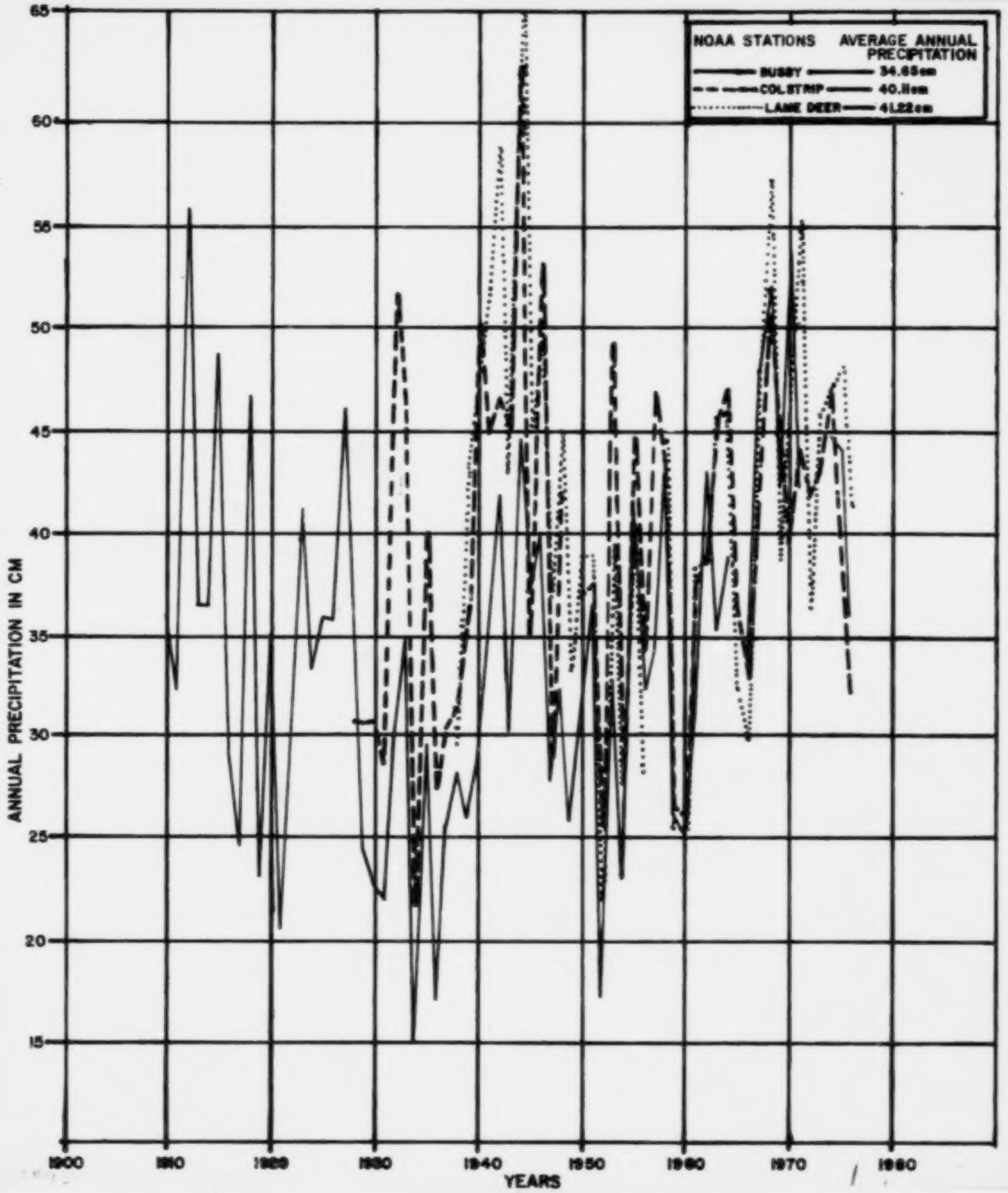


Figure 4.3. Annual precipitation at Busby, Lame Deer and Colstrip VS time.

area by about 330 m (1,000 ft). As a result, winter and summer temperatures are slightly cooler, and annual precipitation is higher than the surrounding lower plains. Precipitation falls principally as rain from late March through October and as snow from November through mid-March.

Precipitation data have been recorded at Busby since 1908 and at Lame Deer since 1938. The annual precipitation extremes recorded at these two stations are listed in Table 4.1. Review of National Oceanic and Atmospheric Administration records indicate Lame Deer has an average annual of 42.49 cm (16.73 in) of precipitation per year and Busby receives an average annual of 34.48 cm (13.97 in) per year. Four NCRP remote continuous precipitation recording stations have been in operation since the spring of 1976. Analyses of these records indicated that the largest amounts of precipitation were recorded in the western and higher central uplands of the region, with the smallest amount being recorded in the lower Tongue River Valley at Tipi Ranch (#4). Seasonally, over 60 percent of the annual precipitation falls between March and July. Monthly totals for the NCRP and NOAA stations on the Reservation are presented in Table 4.2. Records for each of the NCRP stations are incomplete. In most cases the lack of record is attributable to battery powered clock malfunction caused by battery failure during periods of sub-zero temperatures. Future projects in this region should utilize direct electric, mechanical clocks or daily operator-attended stations for the collection of data.

TABLE 4.1 SUMMARY ANNUAL PRECIPITATION: MAXIMUM AND MINIMUM

Readings in cm (in)

	Maximum		Year	Minimum		Year
Busby	55.83	(21,98)	1912	15.16	(5.97)	1934
Lame Deer	65.46	(25.77)	1944	25.50	(10.40)	1960

Evaporation data for the Reservation were gathered from two NCRP installed Class A evaporation stations (E), E #1 and E #2, located at Tipi Ranch in the Tongue River Valley and in Lame Deer, respectively. Station E #1 was installed in July, 1976 and Station E #2 was installed in August, 1976. Station E #1 was operated in 1976 until November and Station E #2 was operated until the end of October. In 1977 Station E #1 was operated from May 1 through October 31. Station E #2 was operated in 1977 from June through September, however, operation problems were encountered from July through September.

Monthly pan evaporation, corrected pan evaporation days of record, and corrected daily evaporation rates for the period of record are presented in Table 4.3. Analyses of the complete 1977 records from E #1 show that the maximum evaporation occurred in July and the minimum in October. The 98.4 cm (38 in) of pan evaporation recorded at Tipi Ranch from May to October in 1977 compares closely with the regional figures of 102 to 114 cm (40 to 45 in) reported by Linsley, et al. (1949). Average daily corrected evaporation rates were as high as 0.546 cm per day

TABLE 4.2 MONTHLY PRECIPITATION ON THE NORTHERN CHEYENNE RESERVATION 1976-77 (centimeters)

Precipitation Station and Elevation in meters	1976												1977											
	Jan	Feb	Mar	Apr	May	Jun	Jl	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jl	Aug	Sep	Oct	Nov	Dec
Lame Deer Divide 1280			0.7	7.8	4.6	14.6	2.4	1.4	1.8		3.0				3.6		6.2	4.8	3.0	2.1	5.1	4.6	1.3	1.5
Kirby 1152			1.4	4.5	3.8	10.9	2.1	0.9	2.0	2.9	2.9	0.9	2.1	1.2	1.5	3.9	8.4						2.6	3.0
Muddy Creek 1152			2.2	10.7	5.4			1.0	1.4	3.8	3.4	0.7	3.5	1.7	5.0			4.3	2.1	2.6	3.6	5.2	2.9	3.4
Lame Deer NOAA 1097	1.2	1.3	0.6	8.5	4.8	13.9	2.6	1.6	1.7	2.7	2.2	0.6	2.1	1.8	3.8	0.6	9.8	3.1	2.3	4.6	3.1	5.3	3.0	1.8
Busby NOAA 1036	0.6	2.0	1.0	5.5	4.4	8.4	3.6	1.4	1.6	2.7	2.3	0.9	2.6	0.5	0.8	0.7	8.8	4.3	1.4	3.0	2.9	2.0	1.8	2.8
TeePee Ranch 914		1.0	0.6	4.4	4.5	10.5	1.2	0.6	1.4	1.6	2.2	1.0	1.2		2.0	0.5		5.9	2.6	2.3	2.8	2.2	1.5	1.6

TABLE 4.3. MONTHLY EVAPORATION DATA FOR NORTHERN CHEYENNE RESERVATION

Year	Month	Pan Evaporation (cm) E #1	Pan Evaporation (cm) E #2	Corrected Evaporation (cm x .7) E #1	Corrected Evaporation (cm x .7) E #2	Days of Record E #1	Days of Record E #2	Corrected Daily Rate (cm/d) E #1	Corrected Daily Rate (cm/d) E #2
1976	July	8.252*	-	5.776*	-	11	-	0.525	-
	Aug	23.909	15.851	16.736	11.096	31	31	0.540	0.358
	Sept	14.204	15.936	9.943	11.155	30	30	0.331	0.372
	Oct	8.209	7.912	5.746	5.538	31	31	0.185	0.179
	Nov	0.760*	-	0.532	-	10	-	0.053	-
	Totals	5[illegible].334	36.699	38.733	27.790	113	92	0.327**	0.303**
1977	May	17.437	***	12.206	***	31	***	0.394	***
	June	19.550	***	13.685	***	30	***	0.456	***
	July	24.191	***	16.934	***	31	***	0.546	***
	Aug	17.607	***	12.325	***	31	***	0.398	***
	Sept	11.450	***	8.015	***	30	***	0.267	***
	Oct	8.169	***	5.718	***	31	***	0.184	***
	Totals	98.404		68.883		184		0.374**	

* Incomplete record for the month
** Average Rate (cm/d)
*** Station failure

(cm/d) in July. Analyses of data collected in 1976 indicate that less evaporation occurred at the Lame Deer Station than the Tipi Ranch Station during the same period of time.

The monthly precipitation data recorded in 1976 and 1977 are compared with the corrected evaporation rate at both stations in Table 4.4. It was found that evaporation greatly exceeded precipitation in months of record from June through October.

TABLE 4.4 MONTHLY PRECIPITATION vs. MONTHLY EVAPORATION

Precipitation (cm)

Year	Month	Tipi Ranch	Lame Deer	Corrected Evaporation - Precipitation E #1	E #2
1976	Aug	0.6	1.6	16.1	9.5
	Sept	1.4	1.7	8.5	9.5
	Oct	1.7	2.7	4.0	2.8
1977	June	5.9	3.1	7.8	-
	July	2.6	2.3	14.3	-
	Aug	2.3	4.6	10.0	-
	Sept	2.8	3.1	5.2	-
	Oct	2.2	5.3	3.5	-

Data collection and analyses efforts of this project concentrated on the identification of the quantity and distribution of precipitation and evaporation on the Reservation. These two factors were emphasized because they are easily measured and they are the principal components of the meteorologic input necessary for analyses of the natural hydrologic system. It is realized that transpiration soil moisture and water stored in the unsaturated zone are important components in preparing detailed water balance relationships. However, because a detailed water balance was not prepared and these parameters are difficult to measure, they were not accounted for directly. Transpiration losses were not measured although it is assumed that transpiration is the highest during the late spring, summer and early fall growing season and near zero during the rest of the year. Surface water runoff and groundwater recharge rates were measured. A discussion of the general relationships and interaction of precipitation, evapotranspiration, groundwater, and surface water as observed during the three year period of this study follows.

Generally, precipitation from November through February is stored as snow pack on frozen ground. Groundwater recharge and surface runoff do not seem to occur during this period, except when warm periods melt snow causing runoff and the ground unfreezes to provide an avenue for groundwater recharge. Groundwater recharge and major surface runoff events occur during the period from March through May, when the majority of the annual precipitation falls and evapotranspiration rates are low. By mid-summer, high evapotranspiration rates, low soil moisture and precipitation, mainly in the form of infrequent thundershowers results in little, if any, groundwater recharge and isolated cases of runoff. In fall, light rains are most likely to be almost completely evapotranspired. By October, stream base flow increases and the surface water temperature decreases indicating the reduction of transpiration rates. The ground becomes frozen and precipitation begins to accumulate as snow.

Specific quantities of groundwater recharge and surface water runoff and their effect of the hydrologic system of the region and Reservation are described in detail in CHAPTERS 6 and 7, respectively.

CHAPTER 5

GEOLOGY

INTRODUCTION

The Northern Cheyenne Reservation lies in the heart of the northern great plains coal province, which contains approximately 37 percent (by weight) of the nation's coal reserves (EPA, 1976). Coal mines in southeastern Montana produce from the Fort Union geologic formation (Figure 5.1); mining on the Reservation would occur in this unit.

This chapter presents the framework upon and through which the surface and groundwater systems flow. The geometry and origin of the rock units on the Reservation are discussed. This, in turn, provides a basis for the following chapters which discuss the interaction of ground and surface water with the geologic framework, and the disruptions mining causes to this system.

The chapter is divided into three major parts - a short description of the general geology of the region; a longer, detailed description of the geologic setting of the Reservation; and a description of three priority study areas containing coal. Supplementary material is presented in Appendix A.

To characterize adequately the geology of the Reservation and to model mining impacts, it is necessary to identify locations of coal at depths shallow enough to be surface mined, and to determine the geometry and characteristics of aquifer systems present on the Reservation.

A detailed model of the near-surface stratigraphy of the Reservation is developed to accomplish these goals, focusing on the coal-bearing Tongue River Member of the Fort Union Formation. The major materials containing and transmitting water - coal, sandstone, clinker and alluvium - are described, and their origin is discussed. Geologic structure and physiography are briefly examined. Results of detailed mapping and drilling in three priority study areas containing strippable coal are described.

The Tongue River Member of the Fort Union Formation is the principal geologic unit at the surface of the Reservation. It contains eleven major coal seams which are continuous over much of the Reservation. Intervals between coal seams consist of interfingering sandstone, siltstone, and shale, in patterns typical of fluvial to upper delta plain environments of deposition. Clinker deposits, produced by burning of coals in the Tongue River Member, cover about one-third of the surface area of the Reservation. Most of the clinker was formed in late Cenozoic time when downcutting by major streams exposed the thick coals of the area. Alluvium up to 37m (120 ft) thick is

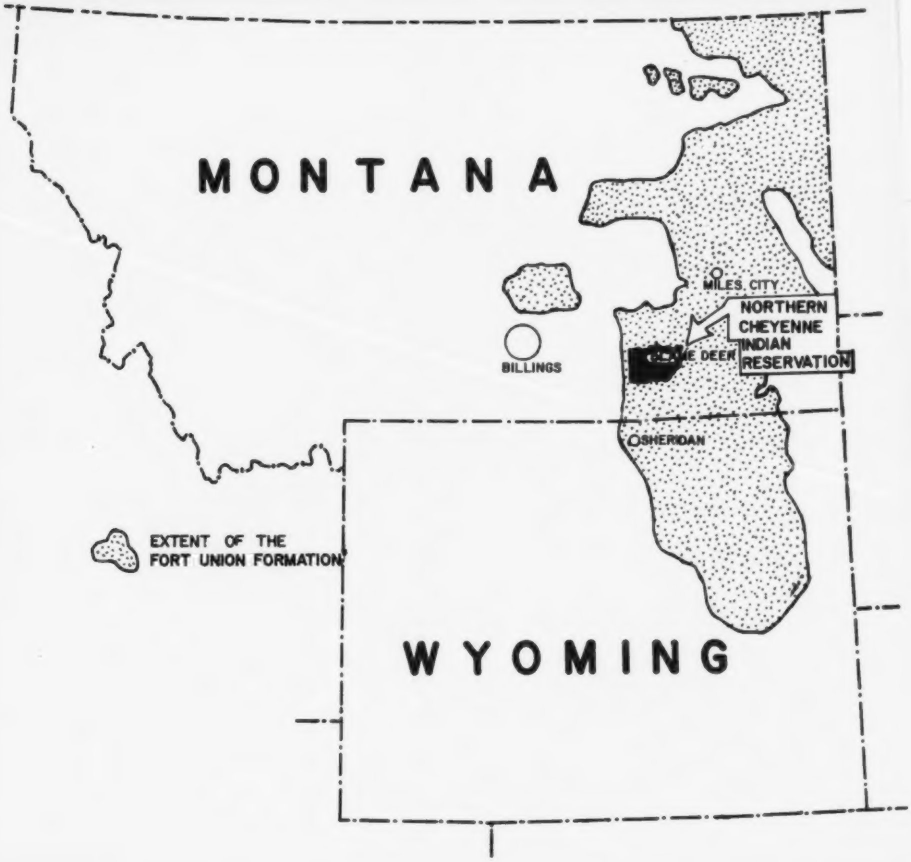

MONTANA
MILES CITY
NORTHERN CHEYENNE INDIAN RESERVATION
BILLINGS
E DEER
SHERIDAN
EXTENT OF THE FORT UNION FORMATION
WYOMING

Figure 5.1. Extent of outcrop of Fort Union Formation in eastern Montana and Wyoming (after Matson and Pinchock, 1977).

present in the valleys of the Tongue River, Rosebud Creek, and their tributaries.

The Reservation lies along the northwestern flank of the Powder River Basin. Strata generally dip less than one degree to the southeast, and minor folds are present. Several normal faults trending N 70°E exist with displacement up to 50m (164ft). These faults may be related to the Lake Basin or Nye-Bowler wrench fault zones. Ten physiographic provinces are delineated based on the surface features of the Reservation area.

Three specific priority study areas containing coal suitable for surface mining are selected for detailed study.

The hydrogeology of:

1) the Logging Creek Priority Study Area in the Tongue River Valley is dominated by the Knobloch coal and clinker, as well as by alluvium;

2) the Buffalo Jump Priority Study Area in the central highlands of the Reservation is dominated by the Anderson coal and clinker;

3) the Indian Coulee Priority Study Area in the Rosebud Creek Valley is dominated by the Rosebud-McKay coals and by alluvium.

PREVIOUS WORK

Although substantial geologic research on coal deposits of southeastern Montana has been published (see Appendix A), coal deposits of the Northern Cheyenne Reservation have been treated so far in a cursory manner. The detailed information which exists is being closely held by companies claiming exploration permits on the Reservation.

USGS research on coal deposits of the Fort Union Formation has been conducted by Dobbin (1929) to the north of the Reservation; Bass (1932) and Warren (1959) to the east; Baker (1929) to the south; Thom *et al.* (1935) and Mapel (1978) to the west of the Reservation. More recent mapping of 7.5 minute topographic quadrangles adjacent to the Reservation has been conducted by Culbertson (1976) and others. These publications, while covering the surrounding area in detail, generally leave out the Reservation lands. Matson and Blumer of the Montana Bureau of Mines and Geology (1973) published a study of strippable coal reserves in selected areas of southeastern Montana (see Appendix A).

The only three studies which deal at all with the geology of the Reservation are from the USGS. The first, by Thom *et al.* (1935) concerns the geology of Big Horn County and the Crow Indian Reservation. Mention of the portion of the Reservation which lies within Big Horn County is confined to a general paragraph on coal and groundwater for each township. The second consists of unpublished fieldwork which Warren and others undertook during the summers of 1938 and 1939. All or parts of ten townships in the eastern half of the Northern Cheyenne Reservation were mapped by plane table method with limited photographic control. Originally scheduled for publication in Warren's (1959) report on *Reconnaissance Geology of the Birney-Broadus Coal Field*, the portion dealing with the Reservation was deleted from the final report. The third, *Status of Mineral Resource Information for the Northern Cheyenne Reservation, Montana*, was published in 1975 by Mapel *et al.* as an administrative report for the U.S. Bureau of Indian Affairs. Because the coal information in this report was essentially a compilation of limited data derived from ten oil and gas wells drilled on the Reservation, the coal reserve estimates were general in nature and no detailed field research was conducted.

Because the previously published geologic work on the Reservation was of limited accuracy and depth, we concluded that further research was needed.

METHODS

Although 56 percent of the Reservation had been leased to companies for coal exploration drilling during 1968 to 1973, the resulting data had either not been given to the Tribe or had been stored in obscure places within the Bureau of Indian Affairs offices. Coal data in the form of lithologic logs, electric logs, drill hole maps, and in some cases derivative maps were acquired by Project staff for Tribal use from Amax, Peabody, Consolidation, and Chevron coal companies, and from land speculators. Due to the proprietary nature of this information, Project staff were unable to use the data directly for this report, although the data was used to check the accuracy of Project field mapping and coal seam correlations.

Copies of previously published geologic reports in the vicinity of the Reservation were secured. Coal seams mapped at the border of the Reservation were traced onto the Reservation. Because coal seam correlations differed from report to report, Project staff synthesized the information and developed a stratigraphic picture based on the most accurate data.

True-color aerial photography was used to aid mapping of the clinker deposits, areas where coal seams had burned and oxidized the rocks to a red color. These areas, in turn, served to pinpoint the location and extent of major coal seams.

Reconnaissance geologic field studies of the Northern Cheyenne Reservation were begun in the summer of 1975. During that time, nearly half the Reservation was mapped, mainly along the eastern, southern, and western edges. Mapping was completed over the remainder of the Reservation during the summer of 1977.

The primary purpose of mapping was to better define the hydrogeologic systems of the Reservation. Individual objectives were:

1. To delineate the areal extent of clinker on the Reservation;

2. To attempt general stratigraphic correlations of coal seams;

3. To learn the geometry of lithologic units exposed on the Reservation;

4. To interpret depositional environments through sedimentary features and fossil evidence;

5. To assess water-bearing potentials of various lithologic units;

6. To define major structural features of the Reservation which may direct groundwater flow; and

7. To determine the extent of alluvium in the major valleys.

A total of approximately 1,000 man-hours were spent from 1975 through 1977 doing reconnaissance field mapping. Traverse density (the ratio of distance traversed per square unit of area) was 0.76 km/km^2 (kilometer per square kilometer) (1.22 mi/mi^2 [mile per square mile]) for the 1975 season and 0.61 km/km^2 (0.99 mi/mi^2) for the 1977 season (which, in addition, reevaluated some areas mapped in 1975).

Additional geologic data for the Reservation were obtained from logs and samples from 51 groundwater monitoring wells constructed by the Project (Figure 5.2). Geologic logs were prepared during drilling, and samples of cuttings were collected every 1.5 m (5 ft). The drilling program also included the collection of six continuous cores of the overburden and coal (Appendix A).

Because of the size of the Reservation and the inherent limitations of time and expense, three priority study areas were selected for detailed investigation (Figure 5.3). Four criteria were used in selecting the sites:

1. Each site must portray a unique geologic and hydrologic setting;

2. Each site must have a potential for the surface mining of coal;

3. The combination of sites should represent the range of geologic and hydrologic conditions present on the Reservation; and

4. All sites must be accessible, with no major obstacles in gaining permission from the surface owner to conduct field research.

Detailed geologic data were available from 42 wells drilled in the selected priority areas. The geologic descriptions of each site are presented in this chapter. The wells will be referred to hereafter in this report as NCRP 24, etc., and their locations can be found on Figure 5.2. Locations will be coded as in the following example: Section 5, Township 3 South, Range 39 East will be written as Sec.5 T3S R39E.

REGIONAL GEOLOGIC SETTING

The regional geologic setting of southeastern Montana and northeastern Wyoming includes the Powder River Basin and adjacent uplifts, such as the Big Horn Mountains, Black Hills, and Miles City Arch. The following section describes the regional structure and the nature of geologic formations which crop out in southeastern Montana in the vicinity of the Reservation.

REGIONAL GEOLOGIC STRUCTURE

The Powder River Basin was formed by the downwarping of the earth's crust in a large part of southeastern Montana and northeastern Wyoming. The basin

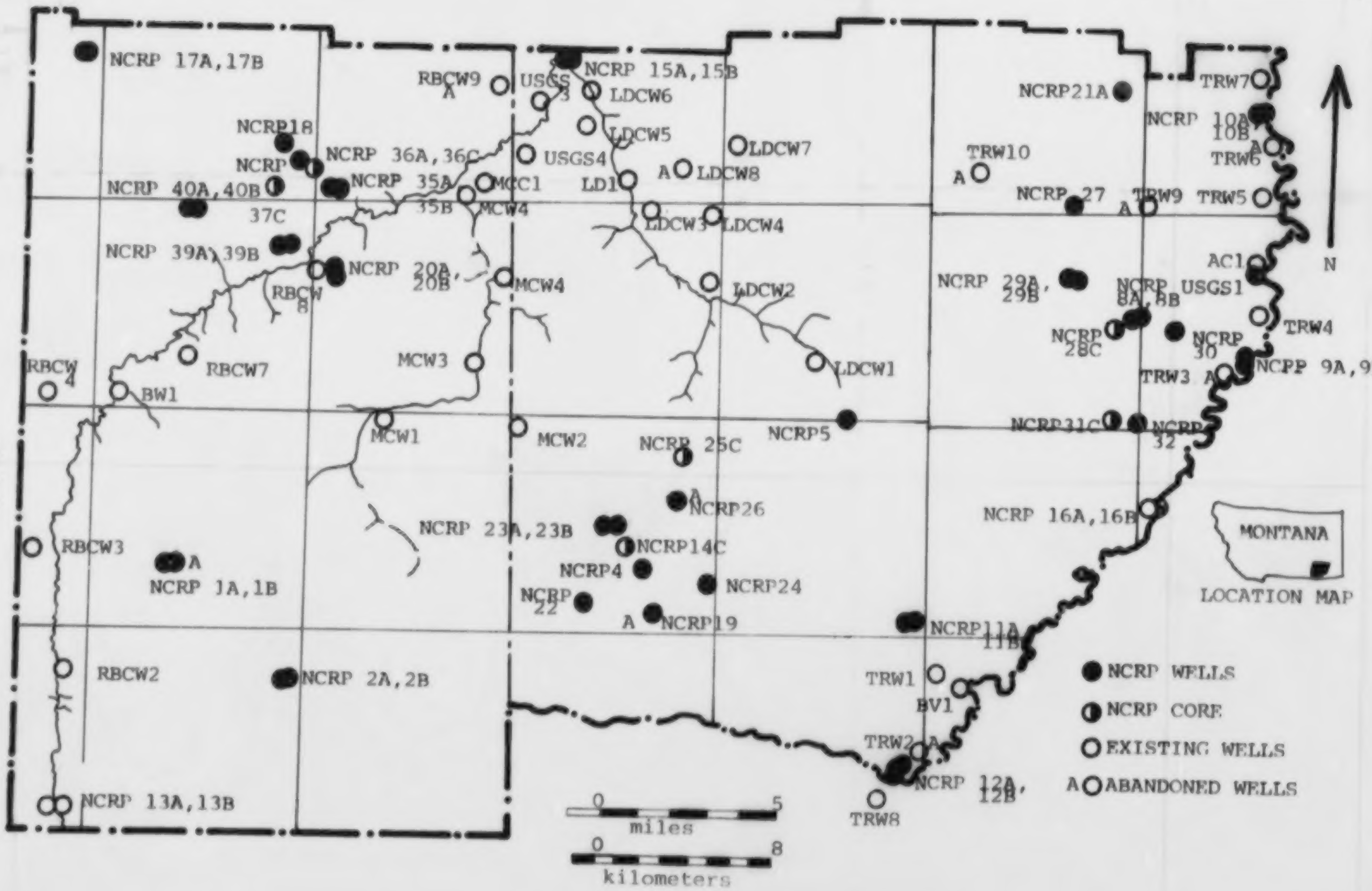

NCRP 17A,17B
RBCW9
A
USGS 3
NCRP 15A,15B
LDCW6
LDCW5
LDCW7
NCRP18
NCRP
NCRP 36A,36C
USGS4
A LDCW8
LD1
NCRP 40A,40B
37C
NCRP 35A
35B
MCC1
MCW4
LDCW3
LDCW4
NCRP 39A,39B
NCRP 20A,20B
RBCW 8
MCW4
LDCW2
RBCW 4
BW1
RBCW7
MCW3
LDCW1
MCW1
MCW2
NCRP 25C
NCRP5
NCRP26
A
NCRP 23A,23B
NCRP14C
RBCW3
A
NCRP 1A,1B
NCRP4
NCRP24
NCRP 22
A
NCRP19
RBCW2
NCRP 2A,2B
NCRP 13A,13B
NCRP21A
TRW7
NCRP 10A,10B
A
TRW6
TRW10
A
NCRP 27
A
TRW9
TRW5
AC1
NCRP 29A,29B
NCRP 8A,8B
USGS1
NCRP 28C
NCRP 30
TRW4
TRW3
A
NCPP 9A,9B
NCRP31C
NCRP 32
NCRP 16A,16B
MONTANA
LOCATION MAP
NCRP11A,11B
TRW1
BV1
TRW2
A
NCRP 12A,12B
TRW8
N
● NCRP WELLS
◐ NCRP CORE
○ EXISTING WELLS
A○ ABANDONED WELLS
0
5
miles
0
8
kilometers

Figure 5.2. Location of NCRP well sites.

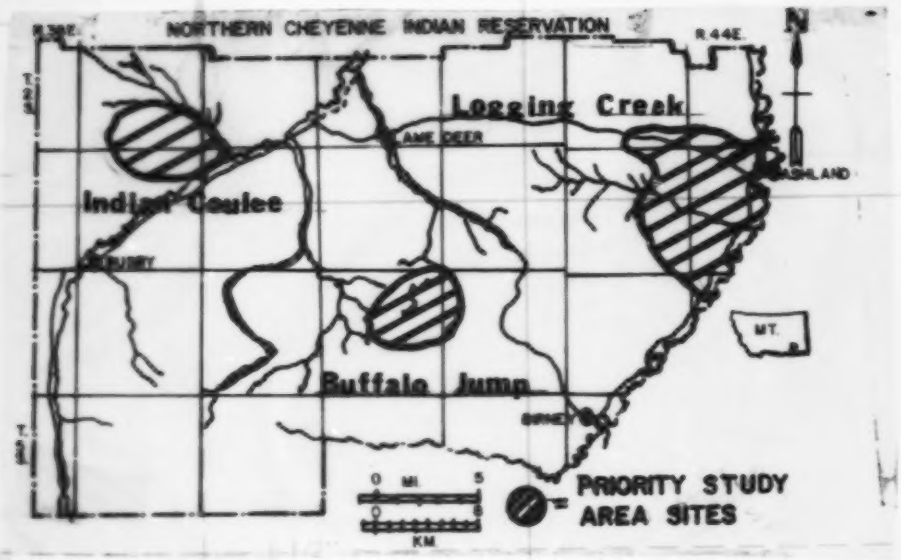


Figure 5.3. Location of the Priority Area Study Sites.

contains an assemblage of Paleozoic to early Tertiary sedimentary rocks which are thickest in the western portion of the basin, near its boundary with the Big Horn Uplift to the west. This uplift and the Black Hills Uplift bordering the basin to the southeast exhibit increasingly older sedimentary formations surrounding a core of Precambrian basement rock. The Miles City Arch and Porcupine Dome mark a gentle rise which separates the north end of the Powder River Basin from the Williston Basin.

Figure 5.4 presents a regional structure map. Most of the following data were interpreted from Lewis and Roberts' 1978 map showing the configuration at the top of the Bearpaw Shale.

The Northern Cheyenne Reservation lies along the northwestern limb of the Powder River Basin. Strata rise fairly steeply to the west toward the Big Horn Mountains. The Ashland Syncline plunges toward the Reservation from the northwest, then flattens out. Another gently plunging syncline trends south-southeast from Lame Deer to Birney where it joins the south-southwesterly plunge of the main axis of the Powder River Basin. This main axis trends along the general course of the Tongue River. Bass (1932) refers to it as the Tongue River Syncline. It steepens towards the south. East of this axis, strata rise fairly gently. Immediately north of the eastern part of the Reservation is a zone of nearly horizontal bedding.

Two strike slip or wrench fault systems (Stone, 1968) of late Pliocene origin (Lewis and Roberts, 1978) with left-lateral movement trend east-southeast across southcentral and southeastern Montana, and are characterized by shear zones of northeast-southwest trending en echelon normal faulting with the

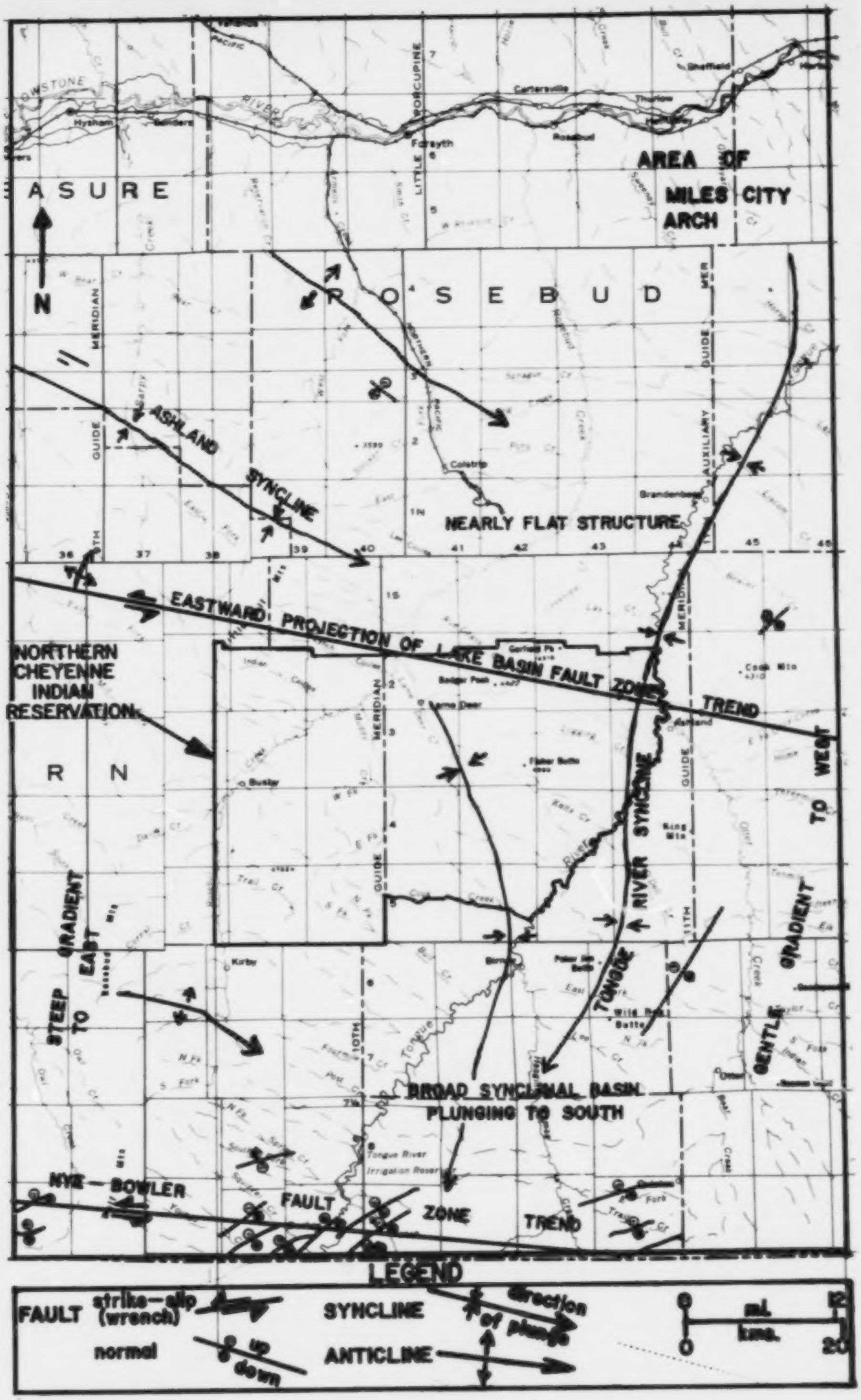

AREA OF MILES CITY ARCH
ASURE
ROSEBUD
N
ASHLAND SYNCLINE
NEARLY FLAT STRUCTURE
EASTWARD PROJECTION OF LAKE BASIN FAULT ZONE TREND
NORTHERN CHEYENNE INDIAN RESERVATION
R N
STEEP GRADIENT TO EAST
TONGUE RIVER SYNCLINE
GENTLE GRADIENT TO WEST
BROAD SYNCLINAL BASIN PLUNGING TO SOUTH
NYE-BOWLER FAULT ZONE TREND
Hysham
Forsyth
Rosebud
Cartersville
Colstrip
Brandenberg
Lame Deer
Busby
Ashland
Birney
Kirby
Tongue River Irrigation Reser.
LITTLE PORCUPINE
GUIDE MERIDIAN
AUXILIARY GUIDE MER.
10TH GUIDE
11TH GUIDE MERIDIAN
36
37
38
39
40
41
42
43
44
45
46
LEGEND
FAULT
strike-slip (wrench)
normal
up
down
SYNCLINE
ANTICLINE
direction of plunge
0
mi.
12
km.
0
20

Figure 5.4. Regional structure in the vicinity of the Northern Cheyenne Reservation, southeastern Montana.

blocks usually downdropped to the southeast (Figure 5.4). The more southerly Nye-Bowler Lineament trends east-southeast across the Montana-Wyoming state line in the vicinity of Decker, where coal exploration has revealed fault zones trending northeast with dipslip displacements of southeast blocks of as much as 61 m (200 ft) (Pederson, 1978). Published information on the second zone, the Lake Basin Fault Zone, shows the shear zone extending from just north of Rapelje, Montana, to 10 km (six mi) NE of Hardin (Ross, et al., 1955). Recent coal exploration in the Sarpy Creek area has extended this zone slightly further east (BIA, 1976). If the trend of the Lake Basin Fault Zone is projected eastward, it will cross the northern boundary of the Reservation. Several fault zones trending N 70°E with vertical displacement of 50m (160ft) or less have been found on the Reservation, especially in the northwestern and southcentral parts.

REGIONAL STRATIGRAPHY

Geologic formations that have been exposed in the vicinity of the Reservation date from the Cretaceous to the Quaternary period. Cretaceous units include the marine sediments of the Judith River Formation and Bearpaw Shale, the shoreline Fox Hills Sandstone, and the continental deposits of the Hell Creek Formation. These units are exposed where the Yellowstone River has cut down to the north, and the Little Big Horn River has eroded to the west of the Reservation. The Paleocene Fort Union Formation, which covers most of the surface of southeastern Montana, is subdivided into three units: the basal Tullock Member, the intermediate Lebo Shale Member, and the uppermost and thickest Tongue River Member, which contains most of the economically important coal seams in the Fort Union. Carmichael (1975) extends a fourth unit, the Sentinel Butte Member, westward from North Dakota to the Pumpkin Creek area 40 km (25 mi) east of the Reservation, due to the abundance of gray shales in that area, and defines it as an upper subdivision of the Tongue River Member. On the basis of fossil correlations, he suggests that the boundaries are time-transgressive, younger in eastern Montana and older in northeastern Wyoming, i.e., the Sentinel Butte Member in Montana may correlate with the Lebo Shale Member in Wyoming.

In this report the Tongue River Member on the Reservation will be treated as a single unit. Regional correlations are summarized in the following diagram from Brown (1962) in Matson and Pinchock (1977) (Figure 5.5).

GEOLOGIC SETTING OF THE RESERVATION

AN OVERVIEW

The Northern Cheyenne Reservation is underlain by approximately 2,740 to 3,350 m (9,000 to 11,000 ft) of sediments (Table 5.1).

Precambrian gneiss forms the underlying basement rock. Stacked above the Precambrian basement are approximately 550 m (1,800 ft) of primarily marine carbonate sediments of Cambrian to Mississippian age, with a minor 8 m (60

TABLE 5.1. STRATIGRAPHY OF THE NORTHERN CHEYENNE RESERVATION*

SYSTEM	SERIES	THICKNESS M (FT)	FORMATION (MEMBER)	DEP. ENV.	LITHOLOGY
Quaternary		0-37(0-120)		Fluvial	Alluvium
		0-70(0-230)			Clinker
Tertiary	Pliocene to Miocene	Thin veneer	Flaxville		Lag gravels on high plateaus
	Eocene	0-31(0-100)	Wasatch		Shale, sandstone, coal
	Paleocene	61-519 (200-1700)	Fort Union (Tongue River)		Shale, siltstone, massive sandstone, thick coal
		122(400)	(Lebo Shale)		Dark shale, minor sandstone
		244(800)	(Tullock)		Shale, sandstone, minor coal
Cretaceous	Upper Cretaceous	61(200)	Hell Creek		Sandstone, shale
		235(770)	Bearpaw	Marine	Shale
		55(180)	Judith River		Sandstone, shale
		104(340)	Claggett		Shale
		210(690)	Eagle-Telegraph Creek		Sandstone, sandy shale
		265(870)	Niobrara		Limy shale
		88(290)	Greenhorn		Shale
		95(310)	Graneros		Shale
		122(400)	Mowry-Thermopolis		Shale, upper part silty and glauconitic
	Lower Cretaceous	21(70)	Newcastle		Sandstone, shale
		27(90)	Skull Creek		Shale
		40(130)	Basal Colorado	Fluvial to Strand	Sandstone, siltstone
		24(80)	Dakota		Sandstone, shale
		43(140)	Fuson		Sandstone, claystone
		21(70)	Lakota		Claystone
Jurassic		34(110)	Morrison		Shale, sandstone
		82(270)	Swift	Strand to Marine	Glauconitic to limy sandstone
		49(160)	Rierdon		Limy shale, limestone
		12(40)	Bowes		Shale
		37(120)	Undivided		Limestone, anhydrite, dolomite
Triassic to Permian		43(140)	Spearfish/Chugwater		Reddish dolomitic silty shale
		31(100)	Goose Egg		Dolomitic silty shale, anhydrite
Carboniferous	Pennsylvanian	27(90)	Tensleep	Marine	Sandstone, dolomite
		27(90)	Amsden		Cherty dolomite
	Mississippian	235(770)	Madison		Massive dolomite and limestone
		116(380)	Lodgepole		Limestone, dolomite
Devonian		43(140)	Undivided		Massive dolomite
Silurian		24(80)	Interlake		Massive dolomite
Ordovician		95(310)	Red River		Massive dolomite
		18(60)	Winnipeg		Sandstone
Cambrian		12(40)	Undivided		Limestone
Pre-Cambrian		?	Undivided	Igneous and Metamorphic	Gabbro and other basement rocks

*Data were assembled from Superior Oil Co. Well No. 22-19, Thom et al, (1935), and NCRP field work.

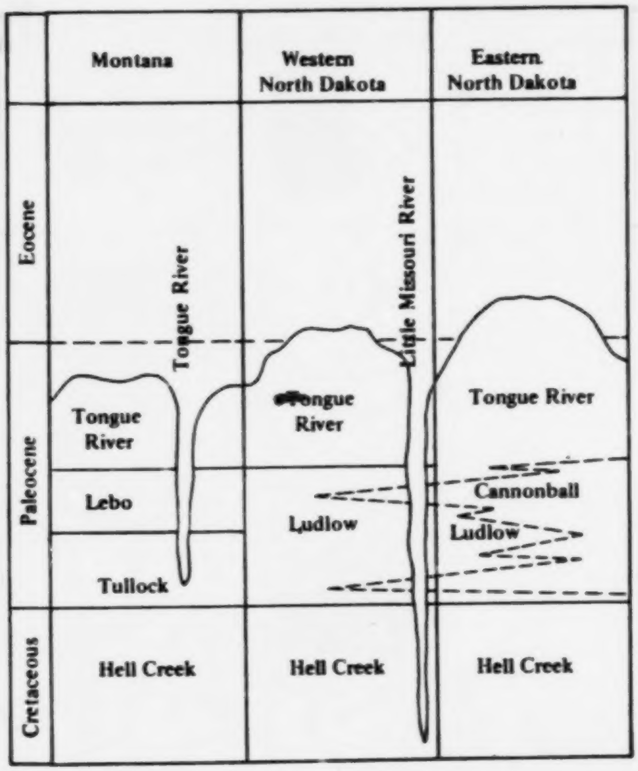

Montana
Western North Dakota
Eastern North Dakota
Eocene
Paleocene
Cretaceous
Tongue River
Little Missouri River
Tongue River
Lebo
Tullock
Tongue River
Ludlow
Tongue River
Cannonball
Ludlow
Hell Creek
Hell Creek
Hell Creek

Figure 5.5. Correlations of late Cretaceous to early Tertiary stratigraphy, Montana to North Dakota (after Brown (1962), in Matson and Pinchock (1977).

ft) thick sandstone bed near the base. Pennsylvanian to Lower Cretaceous strata form a 515 m (1,690 ft) thick sequence of assorted continental red beds, limestones, sandstones, shales, and evaporites representing periodic transgression across an often arid land surface. Several unconformities are present. 1,170m (3,850ft) of Upper Cretaceous rocks form the thickest sedimentary sequence underlying the Reservation. They are mostly shales deposited in a quiet-water marine environment. Minor sandstones between the shales produce oil and gas in various locations in southeastern Montana. Uppermost Cretaceous and Lower Tertiary rocks are non-marine and represent fluvial to strandplain environments. 460 to 980 m (1,500 to 3,200 ft) of sandstones, siltstones, shales, and extensive (predominantly Paleocene) coals are present. Upper Tertiary and Quaternary deposits consist of thin gravel terraces and alluvial fill up to 37 m (120 ft) thick.

Strata exposed at and near the surface of the Northern Cheyenne Reservation are nonmarine and date from the early Tertiary to Quaternary period (Figure 5.6). The Tongue River Member of the Paleocene Fort Union Formation, a sequence generally of laterally discontinuous fine sandstones, siltstones, silty shales and waxy shales, separated by fairly extensive coal seams, covers most of the Reservation. This sequence represents a low-energy fluvial or

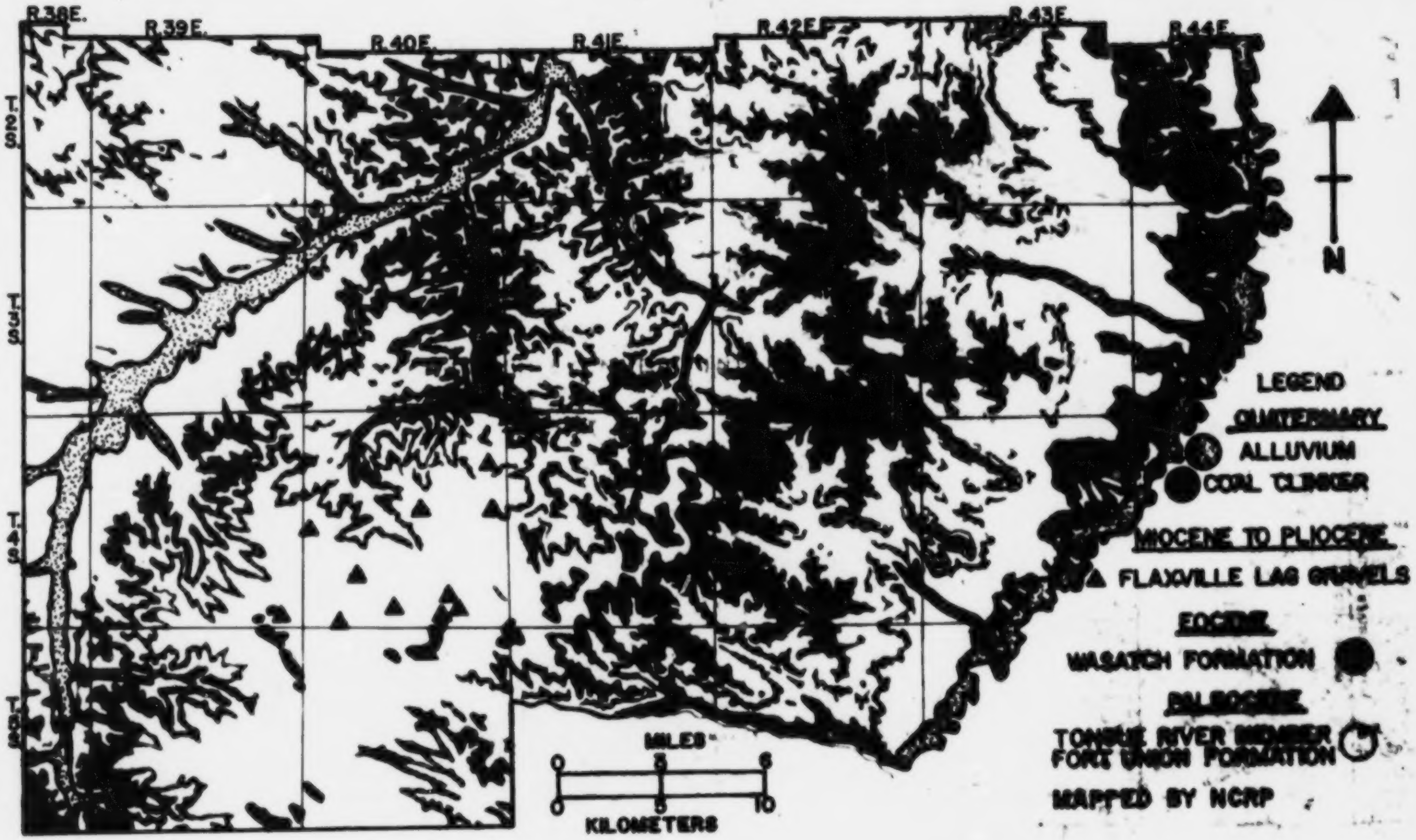

R.38E.
R.39E.
R.40E.
R.41E.
R.42E.
R.43E.
R.44E.
T.2S.
T.3S.
T.4S.
T.5S.
N
LEGEND
QUATERNARY
ALLUVIUM
COAL CLINKER
MIOCENE TO PLIOCENE
FLAXVILLE LAG GRAVELS
EOCENE
WASATCH FORMATION
PALEOCENE
TONGUE RIVER MEMBER
FORT UNION FORMATION
MAPPED BY NCRP
MILES
0
3
6
0
5
10
KILOMETERS

Figure 5.6. Geologic map of the Northern Cheyenne Reservation.

delta-plain environment of deposition. The overlying Eocene Wasatch Formation probably caps a few of the highest knobs in the south-central part of the Reservation. The probable Wasatch strata present on the Reservation are similar in composition to the underlying Tongue River Member, which makes definition of the boundary difficult. The coals of the Tongue River Member have locally burned, and have baked and hardened the overburden into extensive clinker deposits, probably during the Quaternary Period.

Unconsolidated deposits are limited to: 1) thin lag gravels on terraces scattered around the high country in the south-central part of the Reservation, which may correlate with the Miocene to Pliocene Flaxville Formation, or be remnants of intraformational gravels in the Wasatch, White River, or Arikaree Formations; and 2) Quaternary alluvium in the major valleys and terraces adjacent to the Tongue River and Rosebud Creek. Because the Wasatch strata and Tertiary lag gravels are of minor extent, the following description of the geology of the Reservation will focus on the Tongue River Member of the Fort Union Formation and on the Quaternary alluvium, which together contain the major near-surface aquifers.

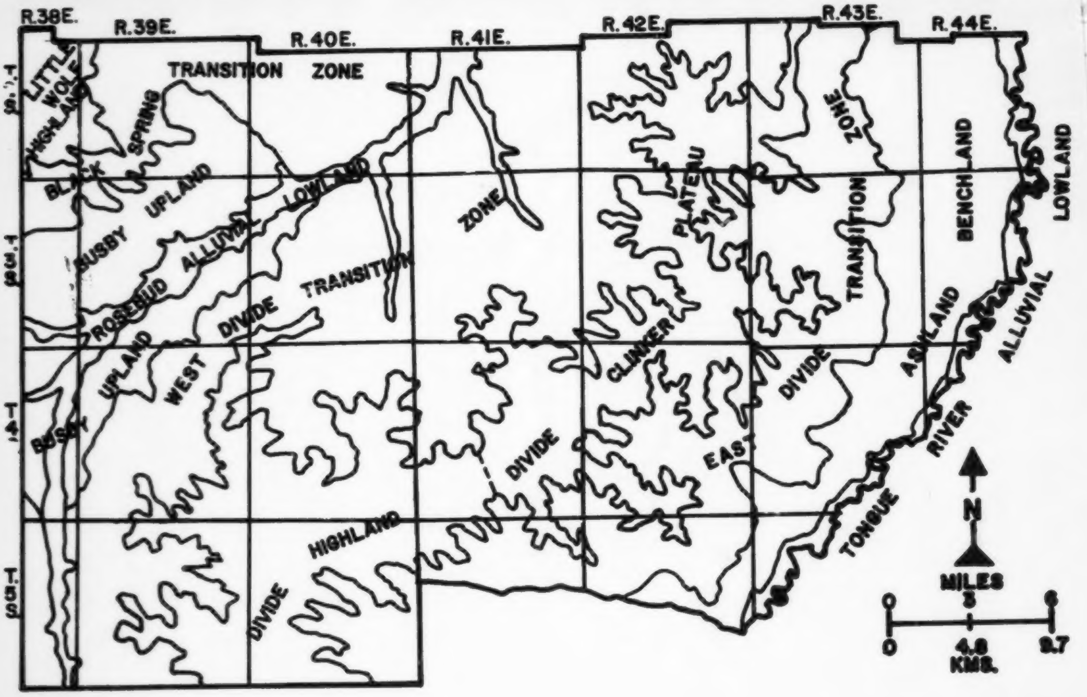
To the south and east of the Reservation are increasingly thick deposits of the Fort Union Formation, overlain by the Wasatch Formation near the Montana-Wyoming border. The Fort Union extends into northeastern Montana. However, to the northwest and west, progressively older formations are exposed where the Fort Union has been stripped away. The lower reaches of both the Tongue River and Rosebud Creek cut into the lower Lebo Shale and Tullock Members of the Fort Union Formation, and the Hell Creek Formation is exposed where Rosebud Creek joins the Yellowstone River.

Quaternary alluvium is exposed in the major river valleys. Scattered river terraces occur at various elevations above present valley level.

PHYSIOGRAPHY

The generally horizontal attitude of the sandstone, shale, clinker, and coal strata is a dominant control factor in the evolution of landforms in the region. The less resistant shales and coals form gentle slopes, and the more resistant sandstones and clinkers form cliffs and cap ridges on the plateaus and bench lands of the Reservation. Ten distinct physiographic provinces have been identified within the Reservation (Figure 5.7). A brief description of each province follows.

The Divide Highland is located in the south-central part of the Reservation and is characterized by gently rolling relief. We believe that this highland area is what is left of an erosional surface present before accelerated down cutting by Rosebud Creek and the Tongue River occurred. This highland grades northeastward into the Divide Clinker Plateau, which is an extensively timbered area underlain by up to 70 m (230 ft) of clinker formed by the burning of the Anderson coal seam. Apparently the resistant clinker surface has retarded the pace of headward erosion into the plateau.
To the east and west of the plateau region are areas of wooded, steep-sided


R.38E.
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R.40E.
R.41E.
R.42E.
R.43E.
R.44E.
T.2S.
T.3S.
T.4S.
T.5S.
LITTLE WOLF HIGHLAND
TRANSITION ZONE
BLACK SPRING
BUSBY UPLAND
ROSEBUD ALLUVIAL LOWLAND
WEST DIVIDE TRANSITION ZONE
UPLAND
BUSBY
DIVIDE HIGHLAND
DIVIDE
PLATEAU
CLINKER
EAST DIVIDE TRANSITION ZONE
BENCHLAND
ASHLAND
TONGUE RIVER ALLUVIAL LOWLAND
N
MILES
0
3
6
0
4.8
9.7
KMS.

Figure 5.7. Physiographic Provinces of the Northern Cheyenne Reservation.

valleys with numerous clinker-capped ridges, identified as the East and West Divide Transition Zones. The East Divide Transition Zone separates the plateau region from the Ashland Benchland, a low flat terrace paralleling the Tongue River. It is postulated that this terrace has been protected from erosion at its eastern edge by the resistant clinker cap formed by the burning of the Knobloch coal seam. To the east of the benchland, the Quaternary alluvial deposits of the Tongue River Alluvial Lowland are found. The Busby Upland in the central western region does not contain extensive clinker and has more rolling topography. The Rosebud Alluvial Lowland, containing the Quaternary alluvial deposits of Rosebud Creek, dissects the Busby Upland. To the north, the Black Spring Transition Zone contains clinker-capped ridges and steep valleys, in which headward erosion is occurring. In the northwestern corner of the Reservation is the Little Wolf Highland. A plateau is not present as in the Divide Highland; instead, a series of steep hills is found. Apparently erosion of clinker capping these hills exposed less-resistant sediments and promoted rapid erosion.

STRATIGRAPHY

Purpose and Scope

One of the original Project goals was to define the characteristics of the strata through which water would pass in potential coal mining operations conducted on the Reservation. Because the Tongue River Member of the Fort Union Formation is the primary geologic unit which would be disrupted during mining, it was felt that a detailed description of the stratigraphy and geometry of this unit on the Reservation was necessary, as well as shorter descriptions of other near-surface units of Tertiary to Quaternary age. The major occurrences of coal and clinker on the Reservation needed to be documented in order to predict where mining would most likely occur, and where priority study sites should be located.

Paleocene Series - Fort Union Formation

Tullock Member

Two lower members of the Fort Union Formation, the Tullock and the Lebo Shale, underlie the Tongue River Member. Although not exposed on the surface of the Reservation, both are present in the subsurface at shallow depth.

The Tullock Member, which is composed of fine, light gray sandstone, shale, and lenticular coal beds, varies from 84 to 137 m (275 to 450 ft) in thickness underneath the Reservation and generally thickens south toward Wyoming. Strata are thin-bedded, giving a banded appearance to surface exposures. The sediments probably formed in coastal plains and lakes (Lewis and Roberts, 1978).

Lebo Shale Member

The Lebo Shale consists of dark gray shale with interbeds of carbonaceous shale, siltstone, and local channel sandstones. Shales contain devitrified volcanic ash and brown ferruginous concretions (Lewis and Roberts, 1978). Thin coals are scattered throughout this member. At its base commonly lies a thick bed of impure lignite, known as the Big Dirty coal (Renick, 1929). The Lebo is conformable with the underlying Tullock, except for local scour channels developed well into the Tullock. Because of its clayey nature, the Lebo is considered an aquitard and supports scant vegetation. Badlands are commonly incised into the gently rolling topography (Bass, 1932).

The Lebo Shale is less than 61 m (200 ft) thick in the northwest part of the Reservation and thickens to the south and southwest, reaching a maximum of 214 m (700 ft) near Kirby. Lewis and Roberts (1978) consider the Lebo to be a deltaic front deposit that prograded to the east.

Tongue River Member

General Characteristics

The relatively flat-lying strata of the Tongue River Member are composed of interfingering sandstone, siltstone, silty shale, and shale beds, as well as eleven major and other thinner stray coal seams. Extensive clinker deposits are present where coal seams have burned. The general stratigraphy of the Reservation, as identified from drilling efforts and field work, is presented in Figure 5.8. A Reservation-wide generalized cross-section of the coal stratigraphy is presented in Figure 5.9.

The Tongue River Member of the Fort Union Formation is easily recognized by the light buff color of its massive sandstone cliffs and by the reddish hue of its clinker outcrops. The interlayering of these comparatively resistant units with less resistant shales results in a cliff and slope topography. Vigorous stands of ponderosa pine and juniper forest are found on the clinker and sandstone outcrops, while grassy to sagebrush covered country overlies the shalier zones.

Sediments of the Tongue River Member on the Reservation are fine-grained, with very little sediment coarser than medium sand. The sandstones, siltstones, and shales generally are laterally discontinuous, and individual units cannot be traced for more than a few kilometers. However, some massive sandstones appear to be more continuous, although spotty in outcrop. Coal seams can be traced continuously over wide areas of the Reservation. However, they split, merge, pinch out, and thicken in a complex manner (Figure 5.10). Gray shale most commonly underlies and overlies coal seams, although this is not always the case. Small, localized pods of impure limestone or calcareous sandstone occur at irregular intervals. The sandstones, coals, and clinkers are commonly water-bearing.

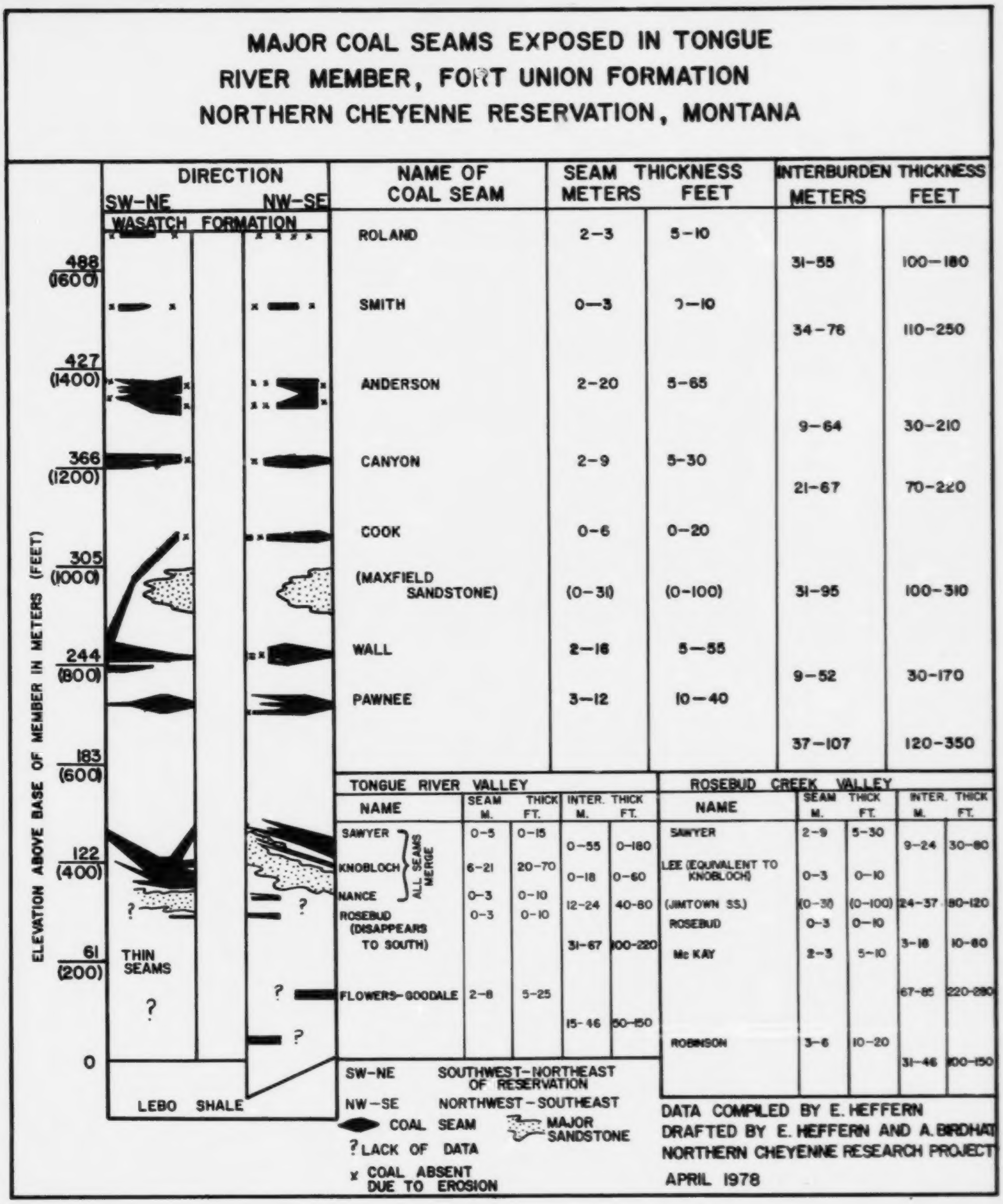
In the highlands of the Reservation where the total thickness has not been reduced by erosion, the Tongue River Member is from 470 to 580 m (1,500 to 1,800 ft) thick, except for the southwest corner where it thins to less than 300 m (1,000 ft), while the Lebo Shale increases in thickness.

Today the Tongue River Member is least thick in the northeastern corner along the Tongue River Valley, where as little as 30 m (100 ft) of alluvium and bedrock cover the underlying Lebo Shale. All but the lowest 60 to 120 m (200 to 400 ft) of the Tongue River Member is worn away in the valley of Rosebud Creek. Along the Tongue River in the southeastern corner of the Reservation, the member is about 180 m (600 ft) thick.

Depositional Environment

The complex stratigraphy of the Tongue River Member is best understood in terms of its depositional environment. Sixty million years ago in Paleocene time, the region was a large complex of swamps and sluggish, meandering rivers similar to the present-day Mississippi River delta. Ancient rivers heading in uplands in the west and central areas of Montana and Wyoming flowed east toward the low-lying area which is now southeastern Montana, where sediments were deposited in a series of deltas. The deltaic systems were composed of overlapping delta lobes. The sediments in the deltas were generally fine-grained, as the coarser sands had settled further upstream.

A delta lobe in a given area consisted of a river channel deposit composed


DIRECTION
SW-NE
NW-SE
WASATCH FORMATION
ELEVATION ABOVE BASE OF MEMBER IN METERS (FEET)
488
(1600)
427
(1400)
366
(1200)
305
(1000)
244
(800)
183
(600)
122
(400)
61
(200)
0
THIN SEAMS
?
LEBO SHALE
SW-NE SOUTHWEST-NORTHEAST OF RESERVATION
NW-SE NORTHWEST-SOUTHEAST
COAL SEAM
MAJOR SANDSTONE
? LACK OF DATA
x COAL ABSENT DUE TO EROSION

MAJOR COAL SEAMS EXPOSED IN TONGUE RIVER MEMBER, FORT UNION FORMATION NORTHERN CHEYENNE RESERVATION, MONTANA

NAME OF COAL SEAM	SEAM THICKNESS METERS	SEAM THICKNESS FEET	INTERBURDEN THICKNESS METERS	INTERBURDEN THICKNESS FEET
ROLAND	2-3	5-10		
			31-55	100-180
SMITH	0-3	0-10		
			34-76	110-250
ANDERSON	2-20	5-65		
			9-64	30-210
CANYON	2-9	5-30		
			21-67	70-220
COOK	0-6	0-20		
(MAXFIELD SANDSTONE)	(0-31)	(0-100)	31-95	100-310
WALL	2-16	5-55		
			9-52	30-170
PAWNEE	3-12	10-40		
			37-107	120-350

TONGUE RIVER VALLEY

NAME	SEAM THICK M.	SEAM THICK FT.	INTER. THICK M.	INTER. THICK FT.
SAWYER	0-5	0-15		
			0-55	0-180
KNOBLOCH	6-21	20-70		
			0-18	0-60
NANCE	0-3	0-10		
			12-24	40-80
ROSEBUD (DISAPPEARS TO SOUTH)	0-3	0-10		
			31-67	100-220
FLOWERS-GOODALE	2-8	5-25		
			15-46	50-150

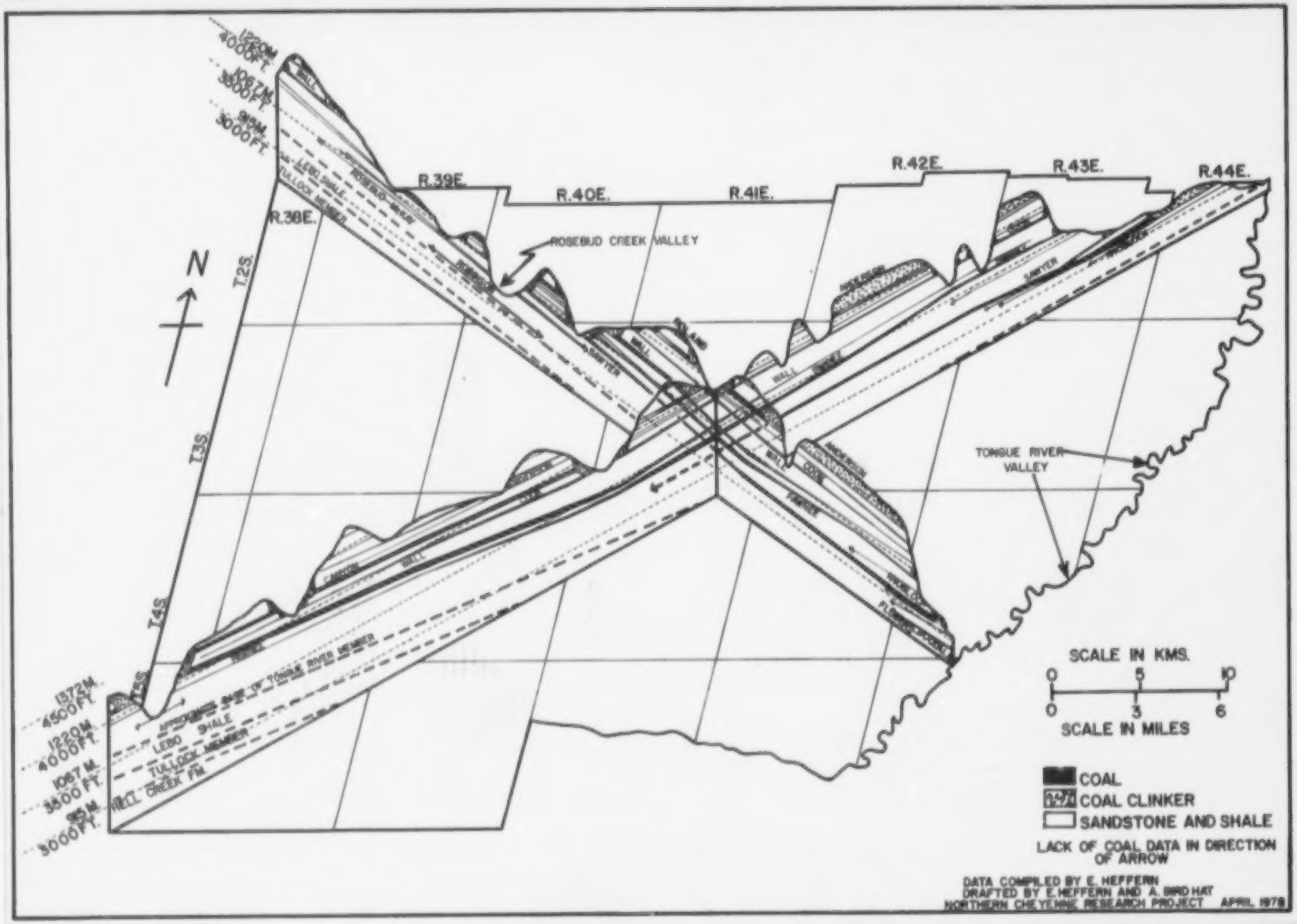
SAWYER, KNOBLOCH, NANCE: ALL SEAMS MERGE

ROSEBUD CREEK VALLEY

NAME	SEAM THICK M.	SEAM THICK FT.	INTER. THICK M.	INTER. THICK FT.
SAWYER	2-9	5-30		
			9-24	30-80
LEE (EQUIVALENT TO KNOBLOCH)	0-3	0-10		
(JIMTOWN SS.)	(0-30)	(0-100)	24-37	80-120
ROSEBUD	0-3	0-10		
			3-18	10-60
Mc KAY	2-3	5-10		
			67-85	220-280
ROBINSON	3-6	10-20		
			31-46	100-150

DATA COMPILED BY E. HEFFERN
DRAFTED BY E. HEFFERN AND A. BIRDHAT
NORTHERN CHEYENNE RESEARCH PROJECT
APRIL 1978

Figure 5.8. Stratigraphic column of major coal seams in the Tongue River Member, Northern Cheyenne Reservation.



1220M.
4000FT.
1067M.
3500FT.
915M.
3000FT.
R.38E.
R.39E.
R.40E.
R.41E.
R.42E.
R.43E.
R.44E.
T.2S.
T.3S.
T.4S.
T.5S.
N
ROSEBUD CREEK VALLEY
TONGUE RIVER VALLEY
LEBO SHALE
TULLOCK MEMBER
ROSEBUD
WALL
SAWYER
ANDERSON
CANYON
KNOBLOCH
FLOWERS-GOODALE
1372M.
4500FT.
APPROXIMATE BASE OF TONGUE RIVER MEMBER
LEBO SHALE
TULLOCK MEMBER
HELL CREEK FM.
SCALE IN KMS.
0
5
10
0
3
6
SCALE IN MILES
COAL
COAL CLINKER
SANDSTONE AND SHALE
LACK OF COAL DATA IN DIRECTION OF ARROW
DATA COMPILED BY E. HEFFERN
DRAFTED BY E. HEFFERN AND A. BIRD HAT
NORTHERN CHEYENNE RESEARCH PROJECT APRIL 1979

Figure 5.9. Generalized cross-section of coal stratigraphy, Tongue River Member, Ft. Union Formation, Northern Cheyenne Reservation.

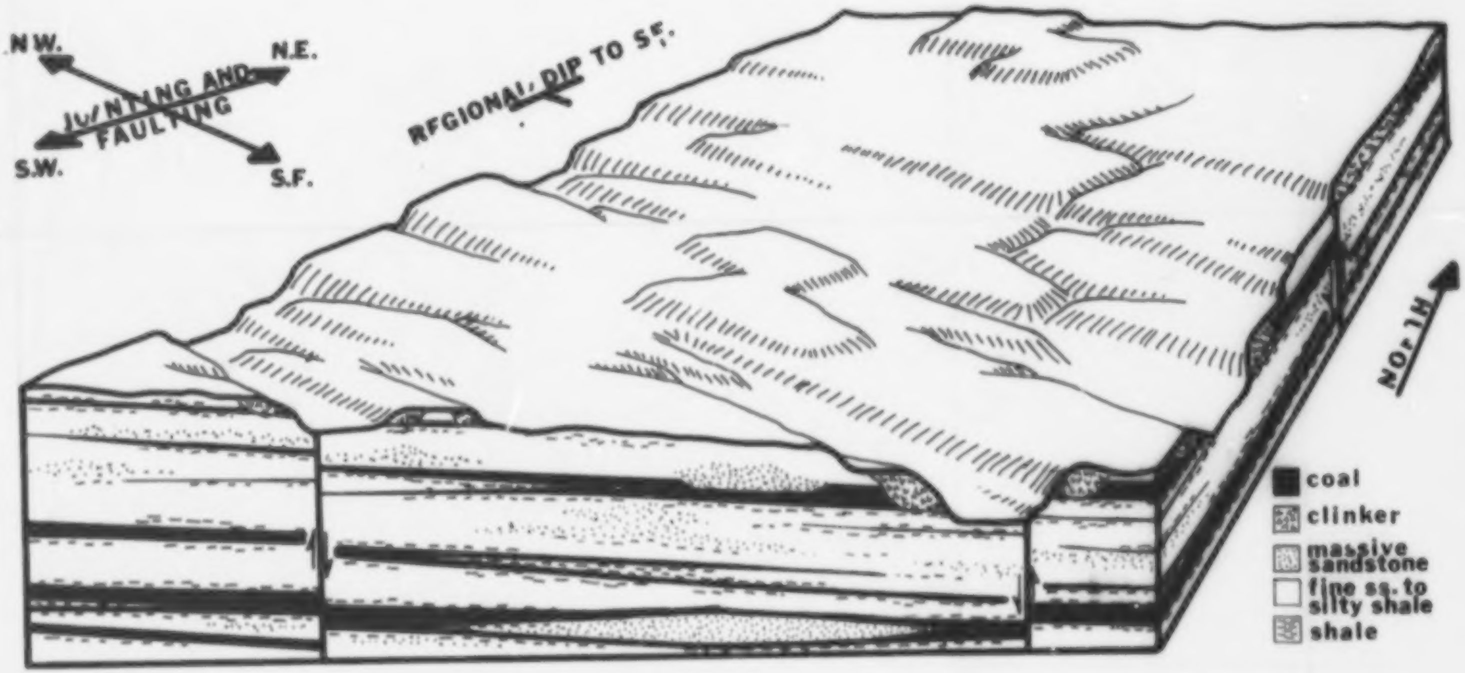

N.W.
N.E.
JOINTING AND FAULTING
S.W.
S.E.
REGIONAL DIP TO SE.
NORTH
coal
clinker
massive sandstone
fine ss. to silty shale
shale

Figure 5.10. Generalized subsurface schematic, Tongue River Member, Northern Cheyenne Reservation.

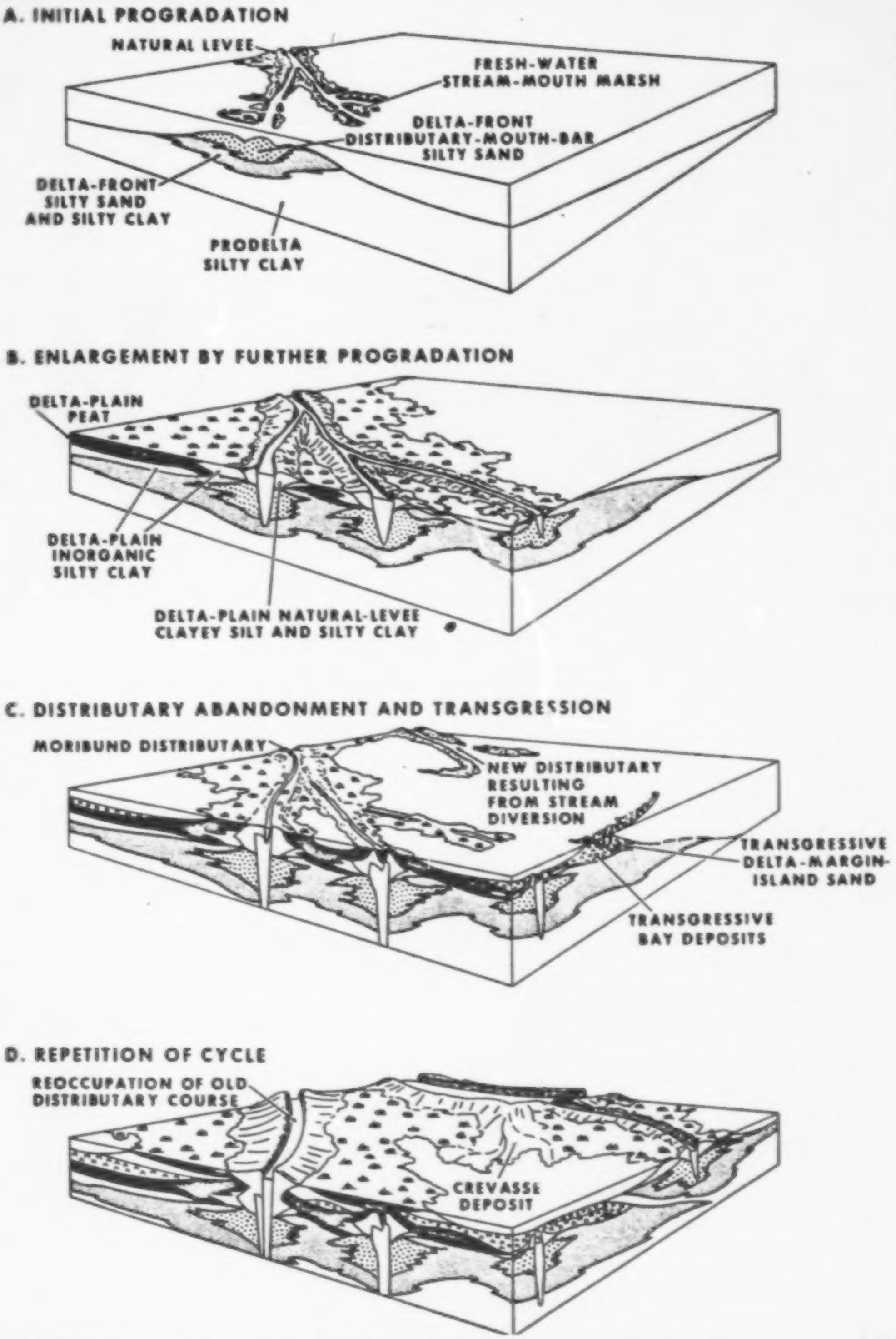
mainly of medium to fine-grained point bar sand deposits, bounded by a levee system of silts and clays. Most of the present-day massive sandstones in the Tongue River Member are believed to be deposits left by these ancient river channels. The levees separated the river from backswamps. Organic material in the well-drained swamps above the water table and nearer the levee was oxidized, and combined with mud washed down from the nearby levee to form clays. Organic material below the water table and further away from the levee was not oxidized, but built up to form peat. Varved lacustrine clays accumulated in backswamp areas that were too deep for plants to grow. These clays and peats lithified to form the present-day gray shales and coals of the Tongue River Member.

The river would often breach its levee during floods, sending sand and mud in the form of crevasse splays into the backswamp. These caused splits in the peat, which today are preserved as splits in the coal seams. If the breach in the levee were large enough, the river would abandon its old course and the crevasse splay would grow to form a new delta. The former delta was abandoned and deprived of clastic sediment; decaying vegetation was the sole material to accumulate.

As the Powder River Basin sank, abandoned delta lobes did not receive enough sediment to counterbalance the rate of depression; thus they slowly sank below the water level. As a consequence, peat in the backswamp slowly prograded over the oxidized clays and, in time, over the levee and channel deposits of the inactive delta. If the region sank faster than the peat accumulated, lacustrine clays prograded over the peat. This process of deposition explains why many coal seams are sandwiched between two layers of shale.

In time, the river shifted its delta back again to the original location and deposited more sand and mud over the peat and shale. River channels scoured out parts of the peat and replaced them with sand. In this way, a new cycle began. These cycles built up over one another to form the extensive series of coal seams and fine clastic units found today in the Tongue River Member on the Reservation (Figure 5.11). (Much of the preceding material on depositional environment has been taken from Weimer (1977), Bass (1932), Land and Weimer (1978), and Matson and Blumer (1977). A more comprehensive discussion is presented in Appendix A.)

The Tongue River Member contains, in places, abundant plant fossils. The best preserved fossils occur generally in tan limy shales and reddish clinkered shales. Although many other shales contain plant remains, they weather away unless the hard limy cement prevents destruction of the fossil evidence, or unless the evidence hardens by baking. The shales, when split apart, yield broadleaf fossils up to 15 cm (6 in) in diameter as well as numerous conifer fossils, a few seed pods, reeds, and occasionally ferns. Fossil plant remains collected by Project staff were identified by Dr. Lee Parker, a paleobotanist with California Polytechnic State University. Species are from fluvial swamp and bottomland, and riparian communities. This indicates a moist, semitropical environment. The species include: Dennstaedita americana (cup fern), Lastrea goldiana (male fern), Equisetum (scouring rush), abundant Metasequoia occidentalis (dawn redwood), Taxodium olriki (bald cypress), Cercidiphyllum



A. INITIAL PROGRADATION

NATURAL LEVEE
FRESH-WATER STREAM-MOUTH MARSH
DELTA-FRONT DISTRIBUTARY-MOUTH-BAR SILTY SAND
DELTA-FRONT SILTY SAND AND SILTY CLAY
PRODELTA SILTY CLAY

B. ENLARGEMENT BY FURTHER PROGRADATION

DELTA-PLAIN PEAT
DELTA-PLAIN INORGANIC SILTY CLAY
DELTA-PLAIN NATURAL-LEVEE CLAYEY SILT AND SILTY CLAY

C. DISTRIBUTARY ABANDONMENT AND TRANSGRESSION

MORIBUND DISTRIBUTARY
NEW DISTRIBUTARY RESULTING FROM STREAM DIVERSION
TRANSGRESSIVE DELTA-MARGIN-ISLAND SAND
TRANSGRESSIVE BAY DEPOSITS

D. REPETITION OF CYCLE

REOCCUPATION OF OLD DISTRIBUTARY COURSE
CREVASSE DEPOSIT

Figure 5.11. Relationship of peat occurrence to delta processes during active and inactive phases of detrital sedimentation in the Mississippi Delta region (after Frazier and Ozanik, 1969, in Weimer, 1977).

arcticum (katsura tree), *Hamamelities inaequalis* (witch hazel), *Sabal powelli* (fan palm), *Platanus raynoldsi* (sycamore), *Planera microphylla* (false sandalwood), *Pterocarya glabra* (Asia walnut), *Viburnum antiguum* and *Viburnum cupanioides*, *Acer silberlingi* (maple), *Cyperacites* (sedge), plus two specimens of unknown leaves or bracts.

Fresh water gastropod and bivalve fossils were collected at two locations by Project staff and identified by Mr. John Hanley of the USGS. Mr. David Glenmore of Busby showed one of these locations to staff members and helped collect samples. These occurrences will be discussed later in the chapter.

Eocene Series - Wasatch Formation

The Fort Union - Wasatch Formation Boundary

The contact between the Tongue River Member of the Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age in southeastern Montana and northeastern Wyoming has been a matter of considerable debate. The unconformity at the base of the Wasatch in the southern part of the Powder River Basin disappears northward, and most commonly the base of the Wasatch in southeastern Montana has been arbitrarily set at the top of the Roland coal seam (Baker, 1929; Matson and Blumer, 1973). A coquina layer which Olive (1957) used as the contact in the Spotted Horse area of northeastern Wyoming cannot be traced northward to the Reservation.

Few geologists have mapped a contact on gross lithologic differences. Denson and Chisholm (1971) state that the heavy-mineral distributions differ between the two formations, but it was not possible for Project staff to recognize such a difference in the high country of the Reservation.

Carmichael (1975) has suggested that the formation boundaries are time-transgressive, becoming younger to the south. If so, this leads to speculation that the lowest Wasatch in this northerly area may be Paleocene in age, although it is Eocene further south in Wyoming.

Wasatch Formation

Extent

If the top of the Roland coal seam is taken to represent the base of the Wasatch Formation, then up to 37 m (120 ft) of the Wasatch Formation is present on the tops of the highest hills in the south-central part of the Reservation (Figure 5.6). The contact is at the 1,310 m (4,300 ft) elevation in the Buffalo Jump Priority Study Area and rises toward the west to 1,440 m (4,720 ft) on the slopes of Crazy Horse Point north of Bull Creek Lookout. To the knowledge of the Project staff, this is the furthest north in the Powder River Basin that the Wasatch has ever been mapped. North of these small remnants, the Wasatch has been completely eroded away.

Lithology

On the Northern Cheyenne Reservation, strata above the Roland exhibit no marked difference from the Tongue River Member below. NCRP 4 encountered brown, gray, and yellow sandstone, coal, and light to dark gray shale above the Roland seam. On the hilltop in the southeast quarter of Sec.11 T4S R41E, and on top of Cook Creek Butte, a thin-bedded resistant sandstone contains many ripple marks and small cross-laminations.

Depositional Environment

The Wasatch Formation was deposited in a time of considerable regional deformation. Sediments were carried down from rising mountain systems to the west, south, and east (the Big Horn, Laramie, and Black Hills Uplifts, respectively) and deposited in rivers and lakes in the developing Powder River Basin. Considerable volcanically-derived sediment may also have been washed eastward into the basin from the Absaroka Volcanics near present-day Yellowstone Park.

Miocene to Pliocene Series - Flaxville (?) Formation

Lag gravels have been found in 14 isolated locations on the high plateau surface in the south-central part of the Reservation (Figure 5.6), up to 450 m (1500 ft) above the present elevations of Tongue River and Rosebud Creek. They may be remnants of river channels associated with an erosional surface of Miocene to Pliocene age, or of an intraformational conglomerate in the Wasatch, White River, or Arikaree Formation.

The cobbles are well-rounded, average five centimeters (two inches) in diameter, and consist of metamorphic and igneous rock types foreign to the bedded rock of the Reservation. Alden (1924 and 1932), Brown (1952), and Prichard and Landis (1975) have assigned high terrace gravels in other areas of eastern Montana to the Flaxville Formation.

Quaternary System - Alluvium and Clinker

Alluvium

Pleistocene to Recent alluvium covers eight percent of the Reservation land surface (Figure 5.6), and is concentrated in the major valleys. It is also present on terraces up to 100 m (330 ft) above the present levels of the Tongue River and Rosebud Creek. The alluvium is up to 33 m (110 ft) deep in the Tongue River Valley, 28 m (90 ft) deep in the Rosebud Creek Valley, 37 m (120 ft) deep in the Muddy Creek Valley, and 28 m (90 ft) deep in the Lame Deer Creek Valley, as determined from logs of domestic and Project wells. Surface area of alluvium of the Tongue River and its tributaries on the Reservation totals 4,777 hectares (11,804 acres). Surface area of alluvium of Rosebud Creek and its tributaries totals 8,971 hectares (22,168 acres). The alluvium consists of varying proportions of gravel, sand, silt, and clay in discontinuous lenses deposited by the stream in the valley.

The Tongue River Valley contains a sizeable percentage of well-rounded igneous and metamorphic gravel derived from the Big Horn Mountains, as well as sand, silt, clay, and less-rounded pieces of clinker and sandstone derived from the local bedrock of the Tongue River Member. Generally, the Rosebud Creek Valley alluvium contains locally derived clay, silt, sand, and gravel, although a small percentage of igneous and metamorphic rocks foreign to the drainage has been observed in a few terrace deposits. Tributary valley deposits below the major clinkered areas generally consist of a high percentage of clinker fragments along with pieces of well-cemented sandstone, and have a lesser proportion of sand, silt, and clay than the major river valleys. Valleys which head above major areas of clinker or where clinker is absent contain cobbles of well-cemented sandstone, along with sand, silt, and clay.

The cyclic process of scouring and filling results in a generally discontinuous sequence of gravel, sand, silt, and clay lenses in the alluvium. River meandering, base level change, and floods all contribute to this discontinuous pattern.

The meandering nature of the major streams controls much of the deposition of gravel, sand, silt, and clay in the alluvium. Sand is deposited on the point bars of meanders, gravel in the stream beds in areas of active stream movement, while the finer silts and clays settle out in quieter backwaters and oxbows. As the meanders shift, lenses of certain lithologies are cut off from additional deposition and overlain by other lithologies.

Changes in base level also alter patterns of deposition. As Pleistocene glaciers shifted the Missouri River drainage from north into Hudson Bay to the east into the Mississippi River system (Alden, 1932), associated scouring of the major tributary valleys, including that of the Tongue River, may have occurred. After scouring, the valleys were filled back up to their present level with alluvium. Scattered terrace deposits above present river level mark periods of deposition at higher base levels.

Flood events are also major factors controlling deposition and erosion. This was amply demonstrated by the record flood of May, 1978. Nineteen centimeters (eight inches) of rain fell in Lame Deer within a period of two and a half days. Floodwaters scoured out about 0.3 meters (a foot) of river bottom sands at a NCRP stream flow gaging station on Rosebud Creek (RBC #2) and left only coarse gravel and boulders in the stream bed. Similar erosion was observed at the NCRP gaging stations on the Tongue River. As a result, lithologic units in the alluvium were truncated, and a new cycle of deposition started.

Clinker

In late Tertiary and Quaternary time, erosion began to expose the major coal seams of the Tongue River Member. Many of these seams ignited and burned back across large areas, baking and hardening the overburden in the process, to form reddish deposits of a rock commonly called clinker. These clinkered areas cover about thirty percent of the Reservation land surface, and are up to 70 m (230 ft) thick. Clinker deposits are discussed at length later in this chapter.

COAL RESOURCES

Introduction

Coal reserves on the Northern Cheyenne Reservation are very large. Almost all of these reserves lie in the Tongue River Member of the Fort Union Formation. On the basis of very limited information, Mapel et al. (1975) estimated a total coal reserve of 23 billion tons, of which 5 or 6 billion tons were strippable. In light of the new information gathered for this report, we feel that these estimates could be revised upward, but the calculations are beyond the scope of this study.

Coal quality on the Reservation ranks at subbituminous C. On an as received basis, the coal contains from 7,600 to 9,100 BTU per pound, 21 to 28 percent moisture, 4 to 11 percent ash, and 0.2 to 1.2 percent sulfur. In general, coal quality increases towards the Big Horn Mountains to the southwest and decreases to lignite to the north and east of the Reservation.

Coal Stratigraphy

The following pages list the major coal seams encountered in the Tongue River Member including special characteristics of interburden, from lowest to highest stratigraphic level in accordance with standard geologic practice.

Basal Sandstone

Bass (1932) describes a massive sandstone occurring in places at the base of the Tongue River Member in the Ashland coal field. This sandstone may correlate with a massive sandstone observed in the Sarpy Creek area, northwest of the Reservation below the Robinson clinker. This stratigraphic horizon is buried below the surface of the Reservation, but a massive sandstone at this level is present in the geophysical log of King Resources Oil Well #1-6 in Sec.6 T5S R41E.

Robinson Coal

Although not exposed on the Reservation surface, the Robinson is present in the subsurface along the valley of Rosebud Creek, where NCRP 35A encounters 5 m (15 ft) of Robinson coal at an elevation of 932 m (3,057 ft) in the Indian Coulee Priority Study Area. At Westmoreland Resource's Absaroka Mine northwest of the Reservation, the Robinson is about 6 m (20 ft) thick, lying approximately 30 to 46 m (100 to 150 ft) above the Lebo Shale (BIA, 1976). The Robinson thins to the east at Colstrip, and is about at the same horizon to correlate with the Terret bed east of Colstrip (Matson and Blumer, 1973). Stratigraphic correlations to the south are uncertain.

Robinson to Rosebud-McKay Interval

In the area of Rosebud Creek, water-producing massive soft gray sandstone, shale, and local thin coal seams are noted in logs from house wells. A 2.4 m (8 ft) thick pebbly zone was encountered in NCRP 35A.

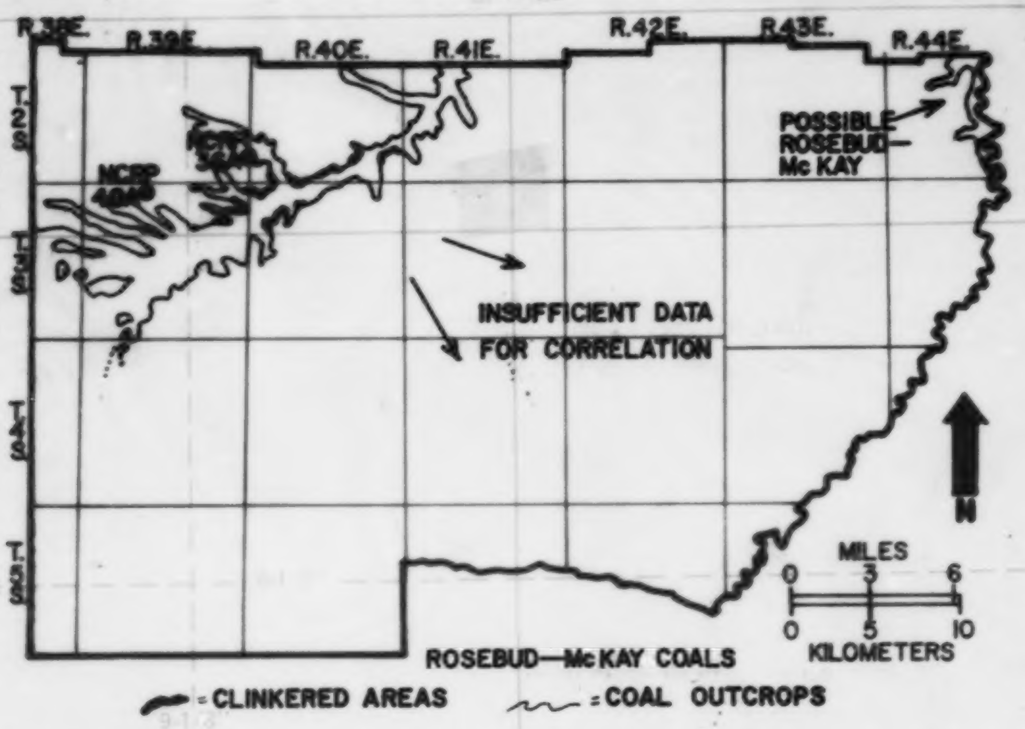
Flowers-Goodale Coal

This coal lies from 76 to 122 m (250 to 400 ft) above the base of the Tongue River Member and 31 to 67 m (100 to 220 ft) below the Nance bench of the Knobloch coal. The Flowers-Goodale is 5.5 m (18 ft) thick at an elevation of 900 m (2,950 ft) in King Resources Oil Well #1-6 in Sec.6 T5S R41E and decreases in elevation to the east. It is present in the subsurface of the Tongue River Valley near Birney Day Village and may be of strippable depth in a few places along the river valley. This bed may split to the northwest to form the Rosebud-McKay coals; however, lack of surface outcrop or drill data prevent correlation.

Rosebud-McKay Coals

The Rosebud-McKay coals crop out along both sides of Rosebud Creek northeast of Busby, where the coals form thin, discontinuous burns. NCRP 36A in the Indian Coulee area encountered 2.9 m (9.5 ft) of Rosebud and 3.1 m (10.0 ft) of McKay separated by 3.1 m (10.0 ft) of shale. To the west, NCRP 40A indicates that the Rosebud splits into thin benches while the underlying McKay remains of fairly constant thickness. The base of the McKay ranges from approximately 1,018 m (3,340 ft) in the southeast part of the Indian Coulee Priority Study Area to 1,098 m (3,600 ft) in the northwest, indicating that the area northwest of Rosebud Creek dips to the east. Coal shown in logs of domestic wells in the lower Muddy Creek Valley to the south may also represent the Rosebud or McKay seams. Correlations with the Rosebud-McKay at Colstrip and Sarpy Creek are tentative.

The thin black lines in Figure 5.12 and the following several figures represent where coal seams crop out; a heavier line, or an area colored in black, represents the area of the coal bed which has burned to clinker. Figure 5.12 shows the areas on the Reservation where the Rosebud-McKay seam crops out (thin lines) or has burned to clinker (heavy lines). It is apparent that most of the outcrops lie in the northwestern corner of the Reservation. Thin burns and coal outcrops 15 to 46 m (50 to 150 ft) below the Knobloch coal along the sides of the Tongue River Valley in the northeastern corner of the Reservation may possibly correlate with the Rosebud-McKay.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ROSEBUD—McKAY COALS
=CLINKERED AREAS
=COAL OUTCROPS

Figure 5.12. Surface outcrop of the Rosebud-McKay coals and clinkers.

Rosebud-McKay to Knobloch-Nance-Sawyer-Lee Interval

This interval is characterized in the northern part of the Reservation by a massive sandstone, perhaps the most extensive in the Tongue River Member. Because of its great thickness, on the order of 30 m (100 ft) along the sides of the Rosebud Creek Valley near Jimtown at the northern Reservation boundary, it has been named the Jimtown sandstone. It forms the "Medicine Rocks" in this area and extends as cliffs along the sides of Rosebud Creek for several kilometers to the southwest. The sandstone is traceable into the Indian Coulee Priority Study Area, and possibly correlates with massive sandstone to the south near the confluence of Trail Creek with Rosebud Creek. The light tan sandstone forms a striking contrast to the overlying Sawyer clinker capping the hills above Rosebud Creek near Jimtown and further north. It seems possible to trace this sand unit eastward to a massive sandstone 15 to 23 m (50 to 75 ft) in thickness immediately below the Knobloch clinker, near the mouth of Reservation Creek in the northeastern corner of the Reservation.

Dobbin (1929) and Bass (1932) both noted the prominent appearance of this sandstone. Dobbin (p. 17) writes:

> "The most prominent sandstone in the Tongue River Member is that which commonly occurs above the Rosebud coal bed. In places this sandstone is 150 feet thick and crops out as a persistent and easily recognized ledge at the base of a yellow bluff of softer sandstone and shale. It is especially developed near Castle Rock, in Miller Coulee, and along Rosebud Creek and its tributaries. In the Rosebud Creek area it is is split into two benches separated by the Lee coal bed. It is grayish-yellow, fine grained, usually massive and arkosic."

Bass (1932) writes:

> "...thick massive sandstones...form striking outcrops of nearly white cliffs, great rounded knobs, and a variety of pinnacles in the western part of the Ashland field and the southern part of the adjacent Forsyth field...finely laminated cross-bedding dipping most commonly eastward and southward...is prevalent."

The above information suggests that this massive sand unit trends eastward and represents a river channel or sheet sand deposit of considerable extent. Domestic well logs in the Lame Deer Creek Valley suggest it is a major aquifer.

Knobloch-Nance-Sawyer-Lee Coals

The Knobloch system comprises a number of separate coal beds which merge near the town of Ashland on the eastern edge of the Reservation. For the purpose of this report, a coal system is defined as all coal seams which merge with or split from one another within the area of the Reservation.

Coals associated with the Knobloch system are some of the thickest on the Reservation and form clinker beds up to 40 m (130 ft) thick along the entire eastern border on the flats just west of the Tongue River (Figure 5.13). Here, west of Ashland, several coal seams from the north, west, and south have merged together in a similar fashion to the merger of the Anderson and Dietz seams to form the thick coal being mined in the Decker area. The depositional environment here may have been a flood basin midway between river levees.

The Knobloch coal reaches its greatest thickness in the Tongue River Valley west of Ashland. NCRP core holes 28C and 31C, near Logging Creek, encountered a main coal bed 14 m (45 ft) thick at an elevation of 940 m (3,080 ft), separated by a few meters of shale and sandstone from a lower bench two to five meters (seven to seventeen feet) thick. To the north, the lower bench merges with the main bed; to the south, the lower bench splits away to form what is called the Nance seam in the vicinity of Birney Village. Near Birney, the main Knobloch itself splits into an upper bed 2.4 m (8 ft) thick at an elevation of 933 m (3,060 ft), separated by 9.8 m (32 ft) of interburden from a middle bed 7.6 m (25 ft) thick, which is separated by 5.5 m (18 ft) of interburden from a lower bed 2.7 m (9 ft) thick (Matson and Blumer, 1973, borehole log DH-3).

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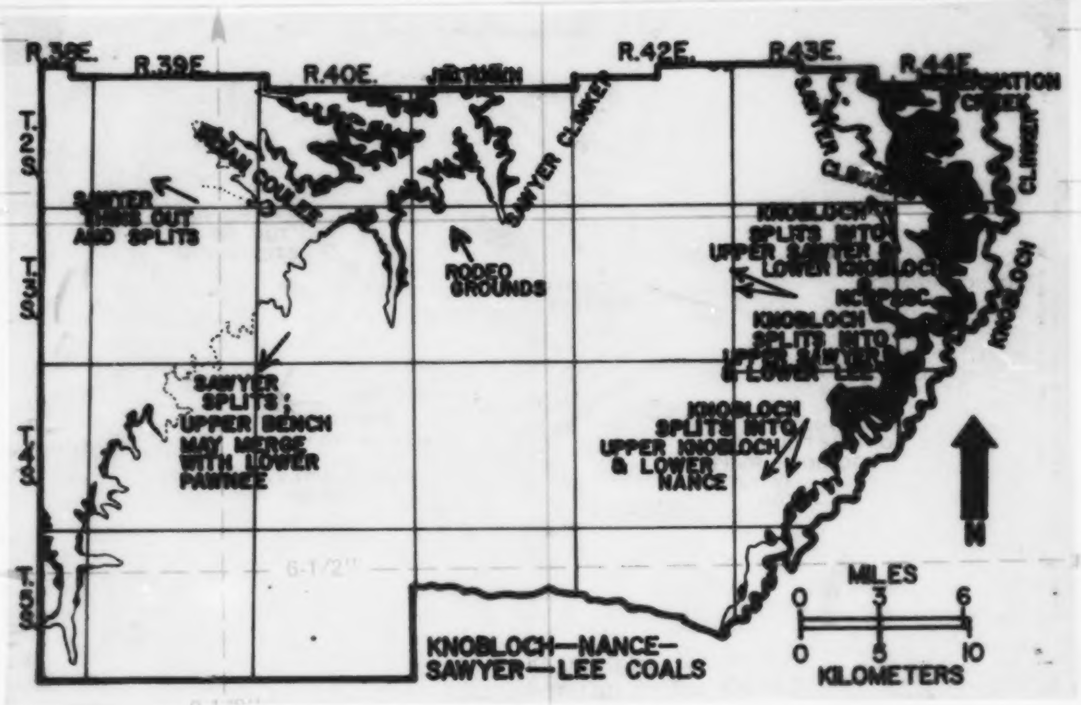
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SAWYER THINS OUT AND SPLITS
INDIAN COULEE
SAWYER CLINKER
RODEO GROUNDS
SAWYER SPLITS; UPPER BENCH MAY MERGE WITH LOWER PAWNEE
KNOBLOCH SPLITS INTO UPPER SAWYER & LOWER KNOBLOCH
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KNOBLOCH—NANCE—SAWYER—LEE COALS

Figure 5.13. Surface outcrop of the Knobloch-Nance-Sawyer

To the north of Stebbins Creek, in the Ashland Benchland west of the Tongue River, an upper bed splits sharply away from the main Knobloch to form the Sawyer coal bed. Both seams rise in elevation towards the northern boundary of the Reservation, where they are separated by about 55 m (180 ft) of interburden. Although the main Knobloch forms the thicker clinker on the Rerservation, it appears to thin out north and west of the boundary. In contrast, the Sawyer clinker can be traced continuously westward through Greenleaf, Miller, and Rye Grass Creek valleys, until it connects with the clinker along Rosebud Creek, that Dobbin (1929), described as Sawyer.

The Knobloch system extends westward from the Tongue River Valley, underneath the Rosebud Creek - Tongue River Divide, and reappears as the thick clinker of the Sawyer coal seam, which caps the sandstone bluffs above Rosebud Creek at an elevation of 1,050 m (3,450 ft). Near the Rodeo Grounds west of Lame Deer the Sawyer has been measured to be 9 m (30 ft) thick (Heffern and Whiteman, 1978). The Sawyer appears to thin out and split west of the Muddy Creek Valley and Indian Coulee, but may merge with a lower bench of the Pawnee coal and continue southwestward to form the lowest major clinker in the Rosebud Creek Valley between Busby and Kirby.

A lower bench called the Lee bed by Dobbin (1929) forms a thin reddish burned zone from 20 to 30 m (70 to 100 ft) below the base of the Sawyer clinker in the Rosebud Creek Valley north of Lame Deer. The Lee bed may correlate either with the Nance bed or the thinned-out main Knobloch. To the

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west, the Lee thins until it is impossible to trace.

Two points of interest should be mentioned. 1)The Knobloch is named after the coal bed mined at the Knobloch ranch along the Tongue River near Birney. The common spelling Knoblock is incorrect. 2) To our knowledge, this report marks the first time that the Sawyer coal has been correlated with the Knobloch. Previously, both beds had been considered to be separate.

Knobloch-Sawyer to Pawnee Interval

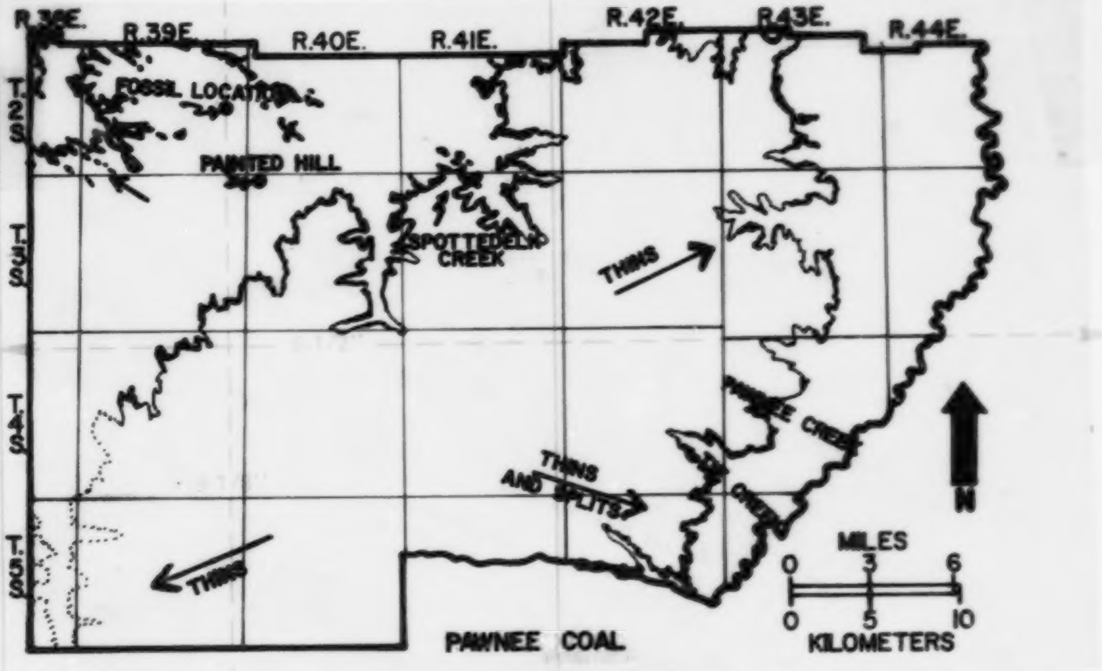
This interval is from 37 to 107 m (120 to 350 ft) thick, generally becoming thicker to the northeast. It is mostly shaly to sandy and thin-bedded, forming flats and occasional badlands in the western part of the Tongue River Valley. In T3S R43E a distinctive tan shale 10 m (33 ft) thick occurs immediately below the Pawnee bed (Warren, unpublished field work, 1939). North of Rosebud Creek in the Indian Coulee area a "striped" zone can be traced. One location in this zone contains a coquina layer rich in snail and clam fossils.

This location, at 1,116 m (3,660 ft) elevation in Sec.24 T2S R39E, is interpreted to lie below the Pawnee seam. The dominant gastropod species at this locality, *Campeloma nebrascensis nebrascensis*, is restricted to the interval below the Wall coal seam in the northern Powder River Basin. This biostratigraphic data supports conclusions of Project field mapping which indicate the Wall clinker occurs above the location where the fossils were found. Other shells found were: *Plesielliptio* sp., *Unionidae*-indeterminate, and *Bivalvia*-indeterminate, all bivalves; and cf. *Campeloma* sp., *Lioplacodes limnaeformis*, and *Lioplacodes* sp., all gastropods. The fossils lie imbedded in a slightly burned shaly coquina interbedded with thin coal layers and a heavy rust-colored sideritic rock.

Several minor coal beds lie within this interval and include the King, Odell, and Brewster-Arnold beds. A bed thought to be the Brewster-Arnold crops out in the extreme southeastern corner of the Reservation but thins abruptly northward. In the Lame Deer area a coal bed from two to four meters (six to thirteen feet) thick appears between the Sawyer and Pawnee seams.

Pawnee Coal

The Pawnee seam is widely exposed over the Reservation, ranging from very thin in the southwest to perhaps 12 m (40 ft) thick in the area of Muddy Creek (Figure 5.14). The Pawnee bed is from 6 to 8 m (19 to 27 ft) thick near Spotted Elk Creek in T3S R41E, and forms a 15 m (50 ft) thick clinker capping the bluffs above the town of Lame Deer. The Pawnee appears to split into at least two benches in the northwest corner of the Reservation at an altitude of 1,170 to 1,220 m (3,850 to 4,000 ft). The Pawnee forms a spotty clinker traceable in the lower part of the bluffs west of the Tongue River. This clinker ranges from 1,010 m (3,300 ft) elevation in the vicinity of Cook Creek to about 1,130 m (3,700 ft) elevation in the Garfield Peak area to the north. The Pawnee appears to correlate east of the Reservation with the Poker Jim bed of Culbertson (1976), the D bed of Bass (1932), and possibly the Pawnee bed of Warren (1959). We think that the Pawnee bed was originally named by Warren in 1939 after exposures in the Pawnee Creek area of the Reservation. South of the Reservation the Pawnee may merge with the Brewster-Arnold bed of Baker (1929). North of the Reservation the Pawnee may correlate the Proctor bed of Dobbin (1929).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FOSSIL LOCATION
PAINTED HILL
SPOTTED ELK CREEK
THINS
PAWNEE CREEK
THINS AND SPLITS
THINS
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MILES
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3
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0
5
10
KILOMETERS
PAWNEE COAL

Figure 5.14. Surface outcrop of Pawnee coal and clinker.

Pawnee to Wall Interval

This interval ranges from 9 m (30 ft) thick in the south-central part of the Reservation to 52 m (170 ft) thick in the southeast. The Birney Sandstone, which forms cliffs up to 24 m (80 ft) high, is exposed at the 1,070 m (3,500 ft) level in the valley of Tie Creek and forms the "sand rocks" on the north side of Spotted Elk Creek at an elevation of 1,070 to 1,100 m (3,500 to 3,600 ft) near Lame Deer. This is thought to be a channel sandstone. Another channel sandstone appears at an elevation of 1,220 m (4,000 ft) in the Little Wolf Highlands.

Wall Coal

The Wall is one of the major coal seams on the Reservation (Figure 5.15). It reaches a thickness of over 15 m (50 ft) in Apache Oil Well #1 and forms a clinker over 30 m (100 ft) thick in the extreme southwestern corner of the Reservation at an elevation of about 1,220 m (4,000 ft). In this area the Cook coal seam is merged with the underlying Wall, accounting for its great thickness, but to the north both beds split off from each other. In the western part of the Reservation the Wall is normally split into a main bed from 6 to 14 m (20 to 45 ft) thick and a lower bench from 2 to 3 m (6 to 10 ft) thick. This lower bench disappears to the east. The Wall clinker is up to 24 m (80 ft) thick in the area of Muddy Creek, but begins to thin east toward Lame Deer. The Wall forms a 9 to 18 m (30 to 60 ft) thick clinker at around the 1,070 m (3,500 ft) level in the valleys of Cook Creek and Black Eagle Fork, in the southeastern part of the Reservation. The Wall thins northward and appears to disintegrate into a "striped" zone of thin pinkish burns and whitish clayey zones at the 1,090 m (3,600 ft) level in Sec.19 T4S R43E; a similar zone was noted along Kelly Creek northeast of Lame Deer in Secs.7-8 T2S R42E. North and east of these "striped" zones the Wall is either very thin or absent. The Wall coal appears to thin in the direction that an overlying set of channel sandstones, called the Maxfield Sandstone, increases in thickness. Perhaps a river channel system represented by the Maxfield Sandstone was developing to the northeast and caused the Wall to thin out, for in the Ashland coal field Bass (1932) notes the Wall is also very thin and a massive channel sandstone is present above it.

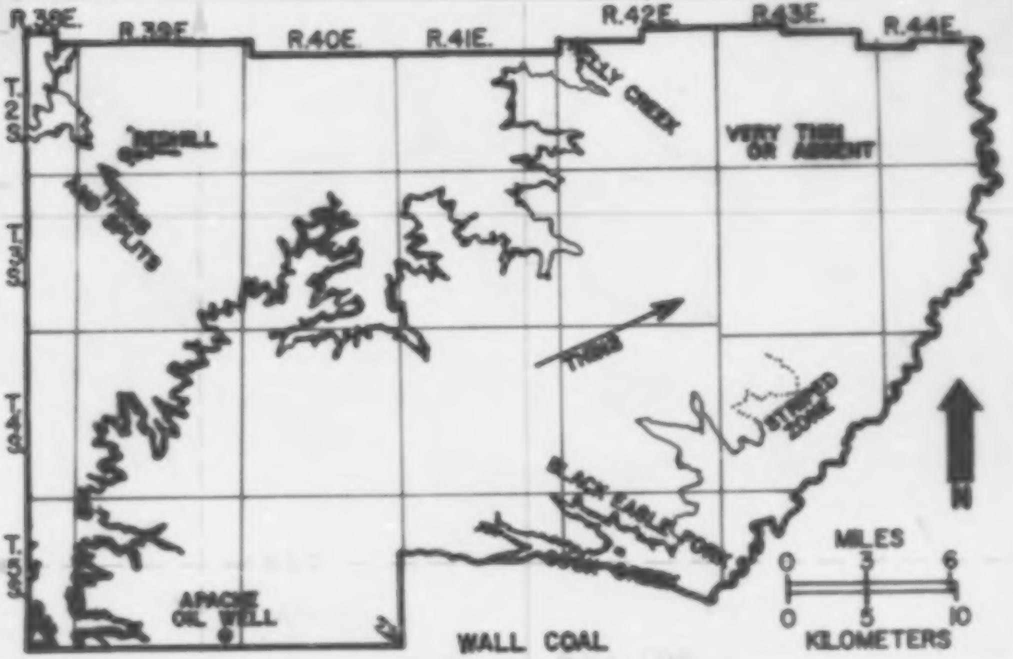
A clinker tentatively correlated with the Wall occurs at the 1,250 m (4,100 ft) level in the northwestern corner of the Reservation, forming the top of Red Hill and other summits in that area.

Wall to Cook Interval

As previously mentioned, a massive sandstone occurs in the northeastern part of the Reservation on the slopes of the divide separating the Tongue River from Rosebud Creek. Project staff have called this sandstone the Maxfield in honor of the late geologist William Maxfield who worked with the Project. It attains a maximum thickness of 34 m (110 ft) a few miles east of Lame Deer in Sec.11 T3S R41E, cropping out from 1,130 to 1,170 m (3,720 to 3,830 ft) elevation as a hill of pinnacles and cliffs capped by pine trees. The sandstone also forms a prominent cliff from 1,160 to 1,190 m (3,800 to 3,900 ft) in elevation on the eastern side of the divide, in the southwest quarter of Sec.21 T2S R43E.

A zone of carbonaceous shale lies along the north side of the west fork of Muddy Creek, in T3S R40E at an elevation varying from 1,170 to 1,200 m (3,850 to 3,950 ft).

The interval above the Wall seam (above 1,280 m (4,200 ft) elevation) in the northwest corner of the Reservation exhibits a "banded" appearance, traceable to Chalky Point and the sides of the Sarpy Mountains north of the Reservation.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T.5S.
REDHILL
THINS AND SPLITS
KELLY CREEK
VERY THIN OR ABSENT
THINS
STRIPPED ZONE
BLACK EAGLE FORK
APACHE OIL WELL
WALL COAL
MILES
0
3
6
0
5
10
KILOMETERS
N

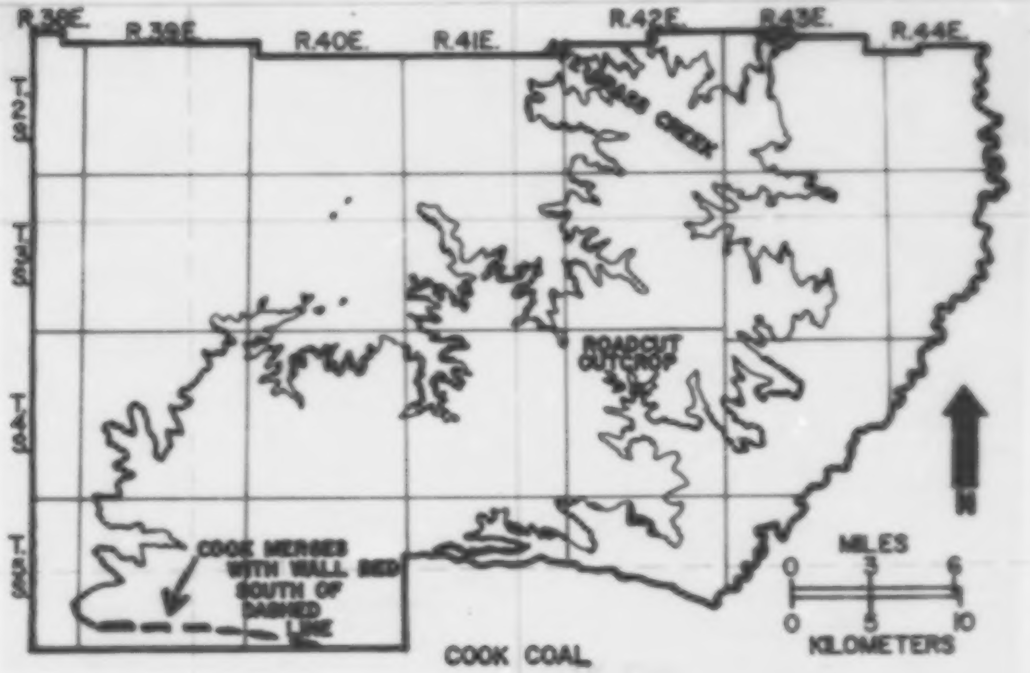
Figure 5.15. Surface outcrop of Wall coal and clinker.

This banded zone is primarily composed of shale and thin-to-medium bedded sandstone, weathering a very light tan with whitish clay streaks and darker zones of thin coal. This area is susceptible to extensive landsliding.

Cook Coal

The Cook coal seam is continuous over most of the Reservation (Figure 5.16). It forms clinkers generally from 5 to 20 m (16 to 66 ft) thick. The Cook lies 30 to 94 m (100 to 310 ft) above the Wall seam, reaching a maximum thickness of about 6 m (20 ft) in a roadcut at the 1,140 m (3,750 ft) elevation on the Lame Deer - Birney highway in the northeast quarter of Sec.16 T4S R43E. It appears that the Cook does not thin to less than 2 m (6 ft) anywhere on the Reservation. In the extreme southwestern part of the Reservation, the Cook merges with the underlying Wall seam. Elevation of the Cook coal ranges from a low of 1,110 m (3,640 ft) in T5S R43E to a high of 1,280 m (4,200 ft) in T4S R39E. The Cook clinker is up to 27 m (90 ft) thick in the vicinity of Rye Grass Creek near the northern Reservation boundary.

Along many of the slopes in T4S R43E, to the east of the Tongue River - Rosebud Creek divide, the Cook and Canyon coals form light-colored burns for an interval of approximately 60 to 75 m (200 to 250 ft) below the base of the Anderson coal. In places these burns merge, coloring the sandstone and shale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CREEK
ROADCUT OUTCROP
COOK MERGES WITH WALL BED SOUTH OF DASHED LINE
N
MILES
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KILOMETERS
COOK COAL

Figure 5.16. Surface outcrop of Cook coal and clinker.

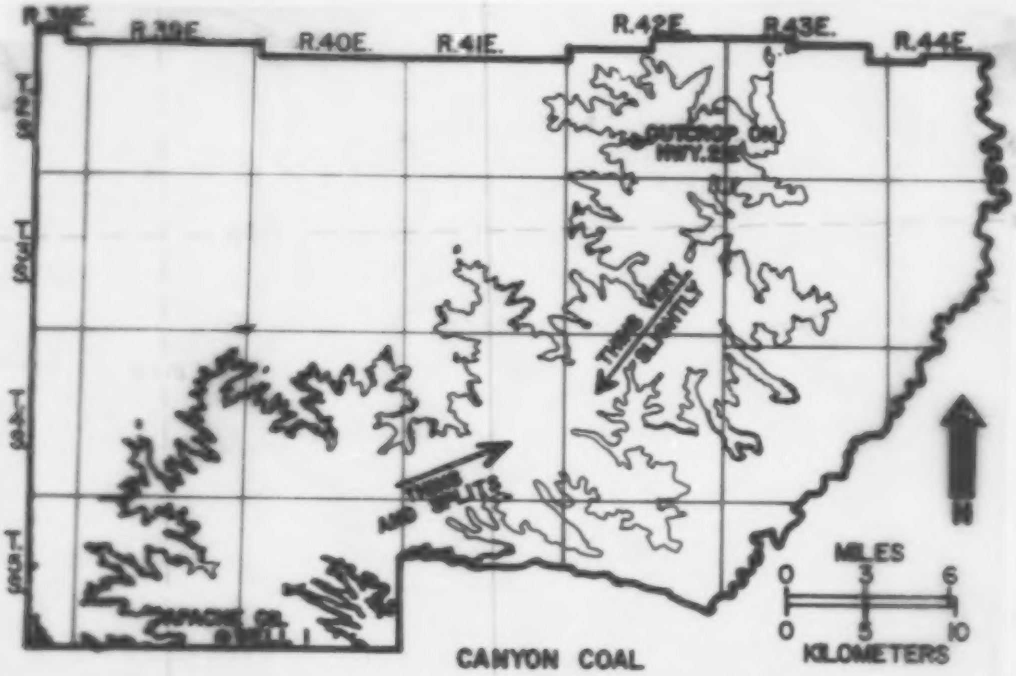
between them pink. The color of the burn is always lighter than the dark red clinker of the much thicker Anderson coal, which caps the ridges. TY1224

To the east of the Reservation, the Cook forms a major clinker, according to Warren (1959) and Culbertson (1976). The Cook may also correspond with the E clinker of Bass (1932) in the Ashland coal field.

Canyon Coal

The Canyon coal seam is widely exposed over the high plateau areas of the Reservation (Figure 5.17). It forms the highest major clinker in the southwestern corner of the Reservation where the coal averages 7 m (24 ft) in thickness (Apache Oil Well #1) and crops out at the 1,280 to 1,310 m (4,200 to 4,300 ft) elevation. A coal seam thought to be the Dietz splits off from the top of the Canyon in T5S R40E, causing the Canyon to thin eastward. In the vicinity of T4S R41E, the Canyon thins and splits to the northeast, then appears to coalesce and thicken somewhat east of R41E, where the Canyon either is exposed or forms a thin burn below the steep bluffs of the Anderson clinker. Approximately 5 m (15 ft) of the Canyon is exposed in a roadcut along U.S. Highway 212 in the southwest quarter of Sec.28 T2S R42E at an elevation of 1,240 m (4,080 ft). In the southeastern part of the Reservation, the Canyon, together with the Cook and a few local beds, forms a slightly pinkish zone below the Anderson clinker. The Canyon is from 21 to 67 m (70 to 220 ft) above the Cook seam and 9 to 64 m (30 to 210 ft) below the Anderson. In the southwest quarter of the Reservation, the base of the Canyon is the source of numerous springs.

South and west of the Reservation, the Canyon forms a major clinker (Matson and Blumer, 1973) that appears to extend at least as far as Decker, Montana. To the east, the Canyon may correlate with the F clinker of Bass (1932) which is 8 to 31 m (25 to 100 ft) thick. Warren (1959) reports the Canyon coal on the Tongue River - Powder River divide is concealed in most places by thick clinker.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APACHE CR.
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KILOMETERS
CANYON COAL

Figure 5.17. Surface outcrop of Canyon coal and clinker.

Canyon to Anderson Interval

A massive sandstone is locally present at around the 1,220 to 1,250 m (4,000 to 4,100 ft) level along the Lame Deer - Muddy Creek divide in the southeast quarter of T3S R41E. A coal seam not over 3 m (10 ft) thick, called the Alderson by Warren (1939), is present in the southern half of the Reservation, and appears from 6 to 15 m (20 to 50 ft) below the base of the Anderson.

Anderson Coal

A coal seam considered to be the Anderson forms a thick coal- clinker unit in the eastern half of the Reservation (Figure 5.18). The thickest area of coal has been almost completely burned to create the most extensive clinker on the Reservation. A high plateau formed by the burning of this bed extends from the summits of Garfield Peak and Charlie Black Butte in the north to the ridgetops above Cook Creek in the south. The clinker, in places, is over 70 m (230 ft) thick; its base rises from 1,170 m (3,850 ft) elevation in T4S R43E to a maximum of 1,290 m (4,220 ft) in the northern part of T2S R42E. Only small "islands" of unburned coal remain underneath hills such as Fisher Butte (southeast quarter of T3S R42E) rising above the general elevation of the plateau. To the west in T4S R41E, the clinker becomes less extensive. A large area of unburned coal is present and forms the Buffalo Jump Priority Study Area.

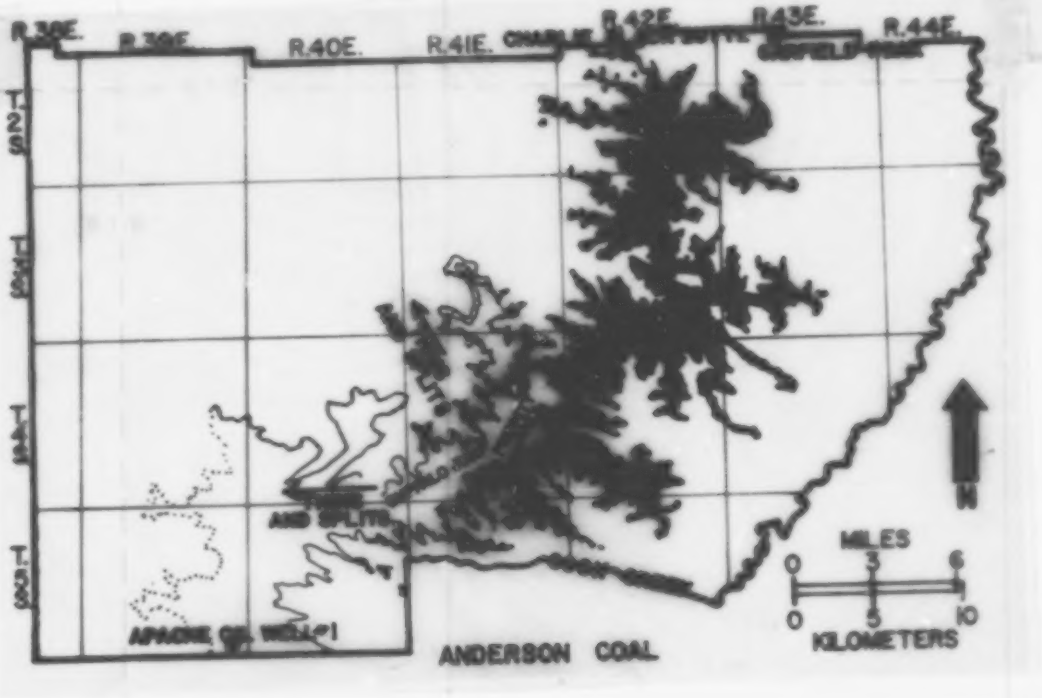

R.38E.
R.39E.
R.40E.
R.41E.
CHARLIE BLACK BUTTE
R.42E.
R.43E.
GARFIELD PEAK
R.44E.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
AND SPLITS
APACHE OIL WELL #1
N
MILES
0
3
6
0
5
10
KILOMETERS
ANDERSON COAL

Figure 5.18. Surface outcrop of Anderson coal and clinker.

Flow structures at the base of this clinker resemble melted lava and indicate very high temperatures at the time of burning. The base of the clinker is the source of many large springs.

At the Buffalo Jump Priority Study Area the base of the Anderson lies at 1,220 m (4,000 ft) in elevation, and NCRP wells have encountered from 13 to 20 m (42 to 65 ft) of coal, generally decreasing in thickness and splitting to the west. These splits thin west and south to under three meters (ten feet) in thickness, where they seldom form clinkers. In the southwest quarter of T5S R39E the upper split is about 2.4 m (8 ft) thick at 1,330 m (4,360 ft) elevation while the lower split is 2.7 m (9 ft) thick at 1,310 m (4,300 ft) elevation (data from Apache Oil Well #1). North of the Buffalo Jump Priority Study Area in the north quarter of T4S R41E and the south half of T3S R41E, the coal also appears to thin and split.

South of the Reservation, the Anderson plus the Dietz beds merge in the Decker area to form a seam from 15 to 24 m (50 to 80 ft) thick. This system can be traced southward to Gilette, Wyoming, where it is called the Anderson-Wyodak coal and is from 18 to over 31 m (60 to over 100 ft) thick (Pederson, 1978).

East of the Reservation, the Anderson clinker correlates with the Garfield clinker, capping Liscom Peak and Home Creek Butte along the Powder River - Tongue River divide (Bass, 1932). Bass named the Garfield clinker after Garfield Peak at the northern edge of the Reservation which is capped by about 18 m (60 ft) of this clinker. Warren (1959) reported that the Garfield has burned throughout large areas in the western part of the Birney-Broadus coal field to form abundant clinker underlying broad high surfaces. Matson and Blumer (1973) reported the Anderson and Dietz coals to merge to the north in the vicinity of Poker Jim Butte (T6S R44E) where a combined thickness of 18 m (58 ft) is encountered. The Anderson clinker may correspond to the clinker that caps the Sarpy Mountains at an elevation of 1,433 m (4,700 ft) in T1N R39E (Dobbin, 1929).

Anderson to Smith Interval

Approximately 15 to 27 m (50 to 90 ft) above the Anderson coal lies a thin-bedded sandstone from one to two meters (three to seven feet) thick, informally called the Bearchum Sandstone by Project staff. It is of seemingly wide extent, ranging over T4S R39E, T5S R39E, T4S R40E, and T5S R40E, and varies from a minimum of 1,290 m (4,220 ft) in elevation in the northeast quarter of T5S R40E to a maximum of 1,370 m (4,500 ft) in the southeast quarter of T4S R39E. The distinguishing feature of this sandstone is its hardness and coherence. In at least two locations it forms a flagstone suitable for construction use. These deposits are about one meter (three feet) thick and can be split into very regular slabs 5 to 15 cm (2 to 6 in) thick and up to 6 m (20 ft) in diameter. The sandstone is light gray with a "salt and pepper" appearance on fresh surfaces, but weathers tan; it is mostly quartzose with a small amount of magnetite and is slightly calcareous. In places, ripple marks are present. In other locations the sandstone does not form regular slabs, but exhibits cross-bedding up to 0.6 m (2 ft) in amplitude. This sandstone can be traced in the field because it is more resistant to erosion than the overlying and underlying sediments. A flat to gently sloping bench forms above it and a steeper slope below. In Sec.33 T4S R40E this sandstone seems to grade into a limestone.

In the northwest quarter of Sec.33 T4S R41E, at an elevation of 1,280 m (4,200 ft), a massive sandstone forms an 18 m (60 ft) cliff over which buffalo were stampeded in prehistoric times. This cliff is capped by one to two meters of cross-bedded, well-cemented, rim-forming sandstone. The lower part of the cliff contains cross-beds that are marked by oxidized magnetite grains which stand out in relief on the sandstone surface. This sandstone can be traced through much of the subsurface of the Buffalo Jump Priority Study Area.

From 34 to 76 m (110 to 250 ft) of interburden separate the Anderson from the overlying Smith coal.

Smith Coal

The Smith coal crops out in the south-central and southwest parts of the Reservation (Figure 5.19). It is generally less than three meters (ten feet) in thickness, and generally contains an abundance of petrified wood. In NCRP 4 in the Buffalo Jump Priority Study Area, the Smith seam is 1.8 m (6 ft) thick at an elevation of 1,290 m (4,240 ft), but thins out toward the northern part of the priority area. The Smith generally rises in elevation toward the west-northwest. The Smith is about 1,390 m (4,570 ft) in elevation in T5S R39E near Bull Creek Lookout. Both Taff (1909) and Baker (1929) report the Smith to occur south of the Reservation.

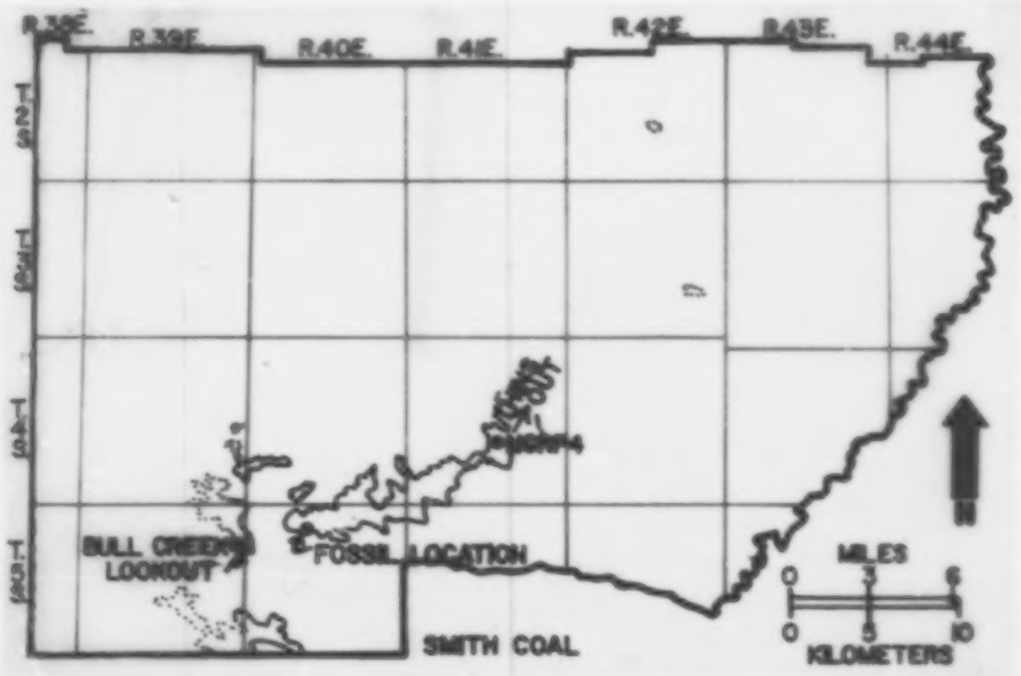


Figure 5.19. Surface outcrop of Smith coal.

Smith to Roland Interval

The Smith is separated from the overlying Roland coal by 31 to 55 m (100 to 180 ft) of sandstone, siltstone, and shale. Project staff found a deposit of fresh water mollusk fossils in a soft tan siltstone immediately above a two meter (six foot) coal seam interpreted to be the Smith in Sec.9 T5S R40E, at an elevation of 1,350 m (4,440 ft). The presence of *Hydrobia eulimoides*, a gastropod thus far known only from the interval between the Smith and Arvada coals in this area, supports the conclusions of Project field mapping which place the fossil location above the Smith seam. Other identified mollusks include: *Plesielliptio priscus*, *Unionidae* - indeterminate, *Bivalvia* - indeterminate, all bivalves; and *Viviparus* sp., *Lioplacodes limnaeformis*, *Lioplacodes multistriata*, *Lioplacodes tenuicarinata*, and *Lioplacodes* sp., all gastropods.

Roland Coal

This seam is widely regarded as the boundary between the Tongue River Member and the overlying Wasatch Formation. No well defined lithologic break appears to exist on the Reservation between the two formations.

The Roland occurs near the top of a number of hills through the south-central and southwest part of the Reservation. It is stratigraphically the highest major coal seam found on the Reservation (Figure 5.20). The Roland coal ranges from 1.5 to 4.6 m (5 to 15 ft) in thickness. It forms a clinker about 12 m (40 ft) thick which caps the Lame Deer - Muddy Creek divide at an elevation of about 1,300 m (4,260 ft) in Secs.27, 33, and 34, T3S R41E, and in Secs.3 and 4, T4S R41E, while forming a thinner burn around Cook Creek Butte, at an elevation of 1,340 m (4,400 ft) in the east half of Sec.1 T5S R40E. The Roland increases in elevation to the west and crops out at an elevation of 1,440 m (4,720 ft) just north of Bull Creek Lookout on the southwestern side of Crazy Horse Point in the northwest quarter of Sec.1 T5S R39E, where it is about 2.4 m (8 ft) thick. Project well NCRP 4 in the Buffalo Jump Priority Study Area encountered 3.7 m (12 ft) of Roland coal at an elevation of 1,320 m (4,320 ft).

CLINKER DEPOSITS

Introduction

Though it is convenient to discuss the geology of the Reservation in terms of the sandstone, siltstone, shale, and coal of the Fort Union Formation, the burning of exposed coal and baking of overburden has significantly altered this formation in numerous areas to a material commonly called clinker. Clinker is easily recognized in the field by its red color. Zones of clinker can be correlated with individual coal seams over large areas, which facilitate geologic mapping. The fractured nature of the clinker provides much space to

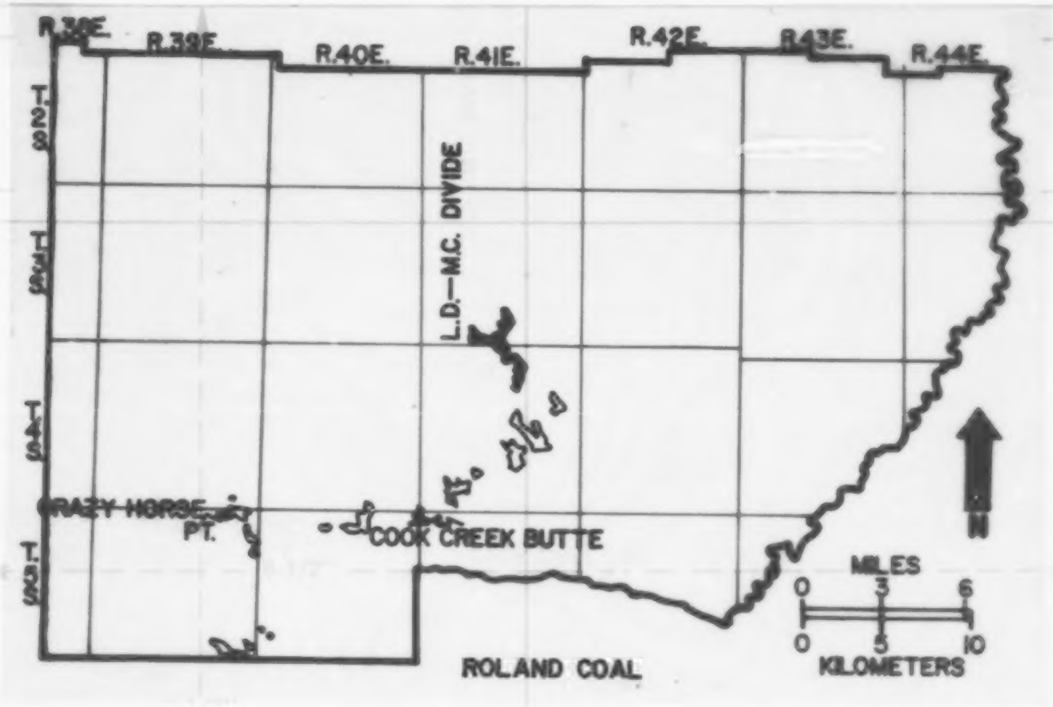


Figure 5.20. Surface outcrop of Roland coal and clinker.

store and conduct groundwater in the region. The burning of major coal seams on the Reservation has left about one-third of the land surface covered by clinker. Because of the uniqueness of this material, its use in correlating coal seams, its hydrologic properties, and its large areal extent, a discussion of the formation, extent, and age of clinker is presented.

Formation

Clinker is generally defined as the coal ash, scoria, and overlying baked rocks which form during burning of coal. Clinker can more properly be termed thermally metamorphosed rock formed by the burning of coal seams and baking of overburden. Typically the overburden has collapsed into the void created when the coal burned down to ash.

Although some hardening of the rock is general to all clinker, many degrees of deformation and coloring are exhibited depending on the temperature to which the rock was subjected and the original grain size and chemical composition of the rock. The rock may show slight baking and reddish discoloration, to partial fusing, to complete melting and recrystallization into scoria.

Bauer (1972) recognized four distinct rock types in the clinker:

1) bedded baked sandstone, siltstone, and shale, colored red by oxidation of magnetite to hematite, among other agents. The sandstone exhibits least deformation or discoloration due to heating, with calcareous sandstone occasionally turning to a yellowish color. Hematite formed by alternation from magnetite is concentrated in cross-bedding zones in sandstone and stands out in striking patterns;

2) fused shale, which turns into a vitreous rock similar to porcelain, and accordingly is termed porcelainite. The phyllosilicate minerals in the shale fuse more readily than the quartz in the sandstone when subjected to high temperatures;

3) rock which has clearly passed through a molten state and has either crystallized into scoria or formed a glass. Vesicular and ropy textures are common and the rock is dark red to black; and

4) conglomeratic siltstone representing baked soil zones.

Rogers (1918) theorized that coal burns could start by lightning, forest fires, or man, but he recognized the most common cause to be spontaneous combustion. Coals which have a high percentage of volatile matter, such as those in the Fort Union Formation, ignite naturally. The fine particle size of weathered coal contributes to the absorption of oxygen necessary for burning to start. Coal which has crumbled from a cliff face and built up a pile at the base large enough to retain heat increases in temperature as oxygen is absorbed until ignition occurs at a temperature of around 150° to 200°C (310° to 390°F).

Once the fire is started in the coal, it burns back into the hillside. In the same way that a ton of coal in a furnace burns down to a small amount of ash, a thick coal bed burns down to a thin residue, leaving a void into which the overburden rock collapses. This collapse generates fractures extending to the surface through the overburden. Trapped superheated gases rise to the surface along the fractures, creating a draft that sucks in air laterally through previously created clinker. As long as this blast furnace can draw in enough oxygen, the coal continues to burn into the hillside. Burning terminates when the oxygen or fuel supply is cut off. This can occur when the overburden becomes too thick to permit the fractures generated by collapse to extend to the surface, when water in the coal bed drowns out the fire, or when the coal bed becomes too thin to burn. Fractures form generally perpendicular to the direction of burn advance, creating a concentric ring of collapse in the resulting depression (Figure 5.21).

Most burns today have died out, although a few are still active. An active burn in the Knobloch seam along Burning Creek (in the northeast quarter of Sec.14 T2S R43E) in the northeastern corner of the Reservation was bulldozed shut several years ago. This writer has observed that the Knobloch is still burning several kilometers northeast of Ashland, even though repeated attempts have been made to smother it using a bulldozer.

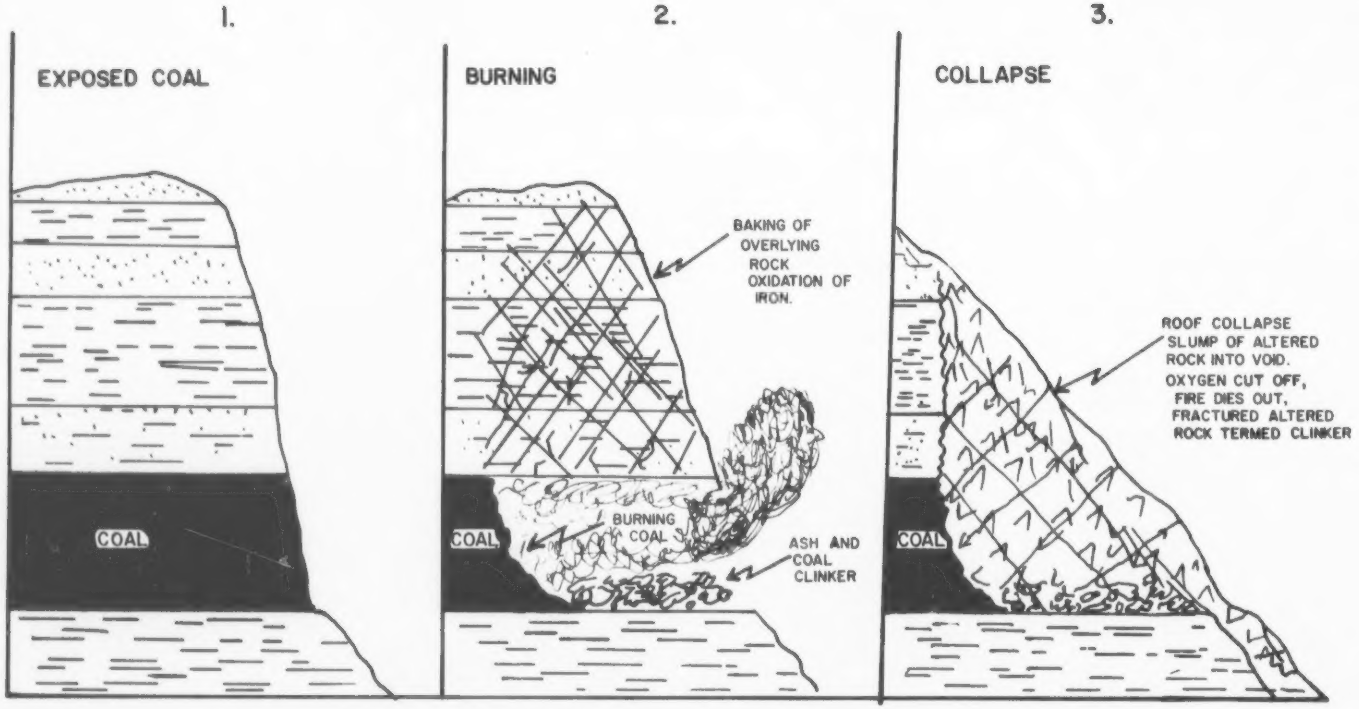

1.
EXPOSED COAL
COAL
2.
BURNING
BAKING OF OVERLYING ROCK OXIDATION OF IRON.
COAL
BURNING COAL
ASH AND COAL CLINKER
3.
COLLAPSE
ROOF COLLAPSE SLUMP OF ALTERED ROCK INTO VOID. OXYGEN CUT OFF, FIRE DIES OUT, FRACTURED ALTERED ROCK TERMED CLINKER
COAL

Figure 5.21. The formation of clinker.

Some of the overburden which falls into the burning coal melts due to the intense heat (around 880° to 1,100°C) (1,616° to 2,012°F) (Griffith, et al. (1960) in Bauer (1972)). This melted lava-like rock then oozes up through the fractured rock or flows through the base of the burn zone until it solidifies as scoria.

A typical cross-sectional view through a zone of clinker (Figure 5.22) would show:

1) an upper sag zone of slightly baked rock which is not fractured enough to collapse extensively;

2) an intermediate zone of collapsed overburden with disoriented bedding between the individual blocks. The resulting breccia is often fused at the edges by once molten material. As superheated gas rose along major fracture zones, the rock adjacent to the fractures melted, and possibly some gas-rich slag was pushed upwards from the base of the burn. This melted rock cooled to form chimneys of erosion-resistant scoria, which crop out as purplish to black veins cutting through less-altered areas of reddish overburden. Pods of whitish calcareous material are found in a few of these chimneys; and

3) a basal zone of purple to black, finely crystalline to glassy, commonly vesicular scoria containing partially melted fragments of overburden, underlain by a layer of tan ash less than one meter (three feet) thick. A thin layer of shale seat rock below this zone may also be burnt.

A wide range in porosity and permeability is possible in clinker depending on how thoroughly fused the overburden has become and on the degree of fracturing which has occurred.

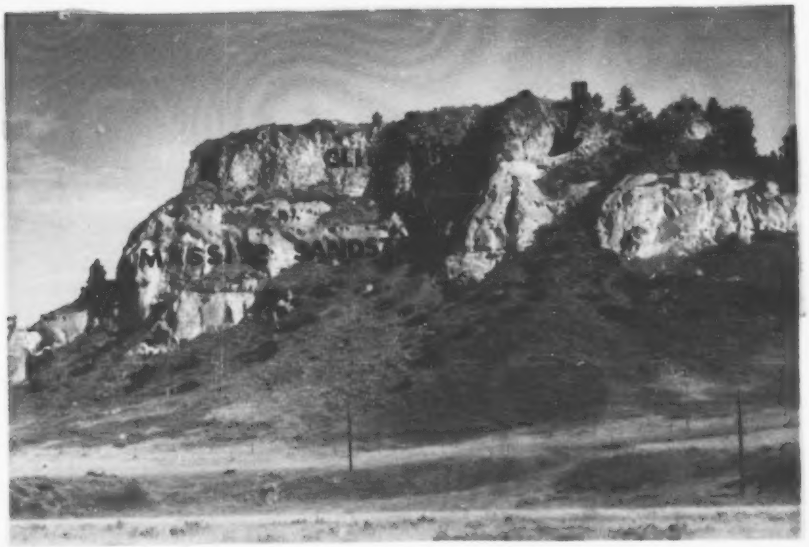
Plates 5.1, a through d, show progressively closer views of the Knobloch clinker above Reservation Creek in the northeastern corner of the Reservation.

Erosion wears away the fractured rock more readily than the hard fused scoria "vents" commonly cropping out as chimneys and scoria ridges along the lower part of clinkered areas. Where two close coal seams have created a single burn, in some places the general (although collapsed) level of the upper seam can be traced along a line of scoria in the clinker.

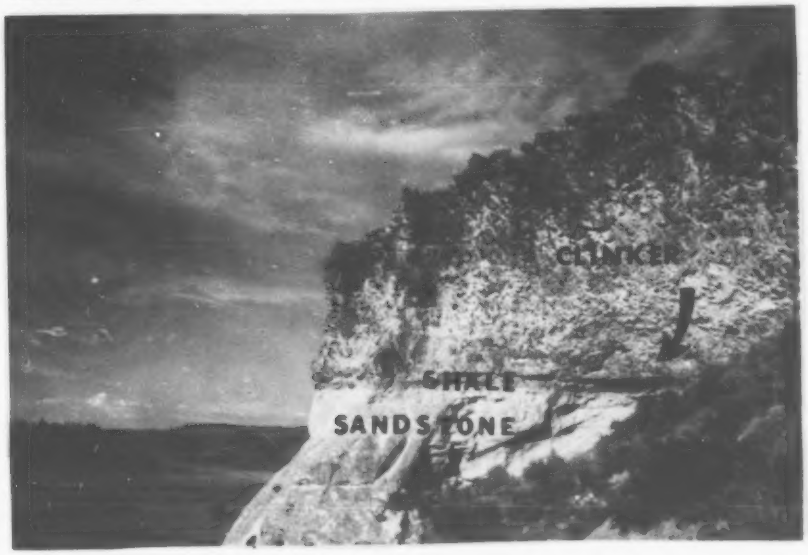
Most of the extensive clinkers on the Reservation probably formed in stages, rather than in one continuous episode of burning. These stages typically involved:

1) initial exposure and burning of the coal bed, and formation of a terrace of clinker;

2) extinguishing of the initial burn;


CLINKER
MASSIVE SANDSTONE

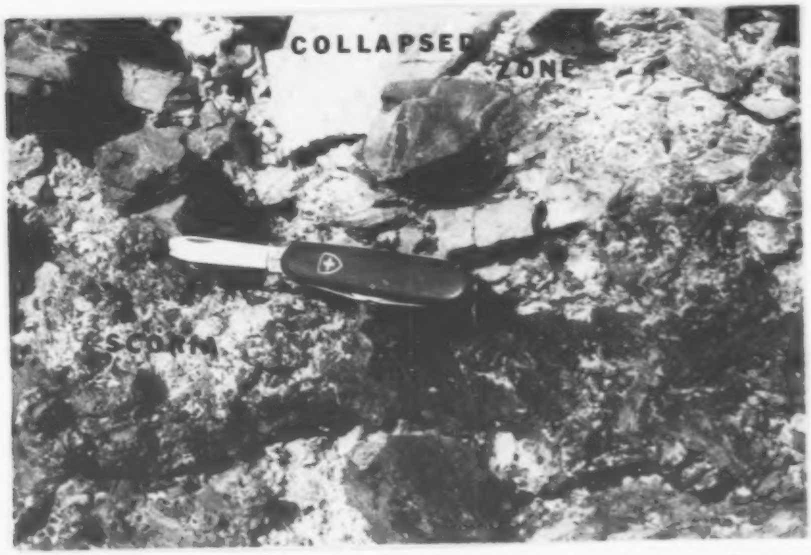
a. Knobloch Clinker near mouth of Reservation Creek at northeast corner of Reservation (SE¼ NE¼ Sec.8 T2S R44E). The clinker is underlain by a massive sandstone which may correlate with the Jimtown Sandstone. Arrows point to increasingly detailed views in pictures a through d.


CLINKER
SHALE
SANDSTONE

b. View of clinker wall, showing its brecciated nature.

Plate 5.1 a through d. Views of Knobloch clinker outcrops.

c. Closeup view of basal contact zone between clinker and underlying shale. Clinker is differentiated by an upper zone of collapsed overburden and a basal zone of scoria produced by melting of the Knobloch coal.



d. Contact between collapsed zone and basal scoria. Note vesicular appearance of scoria and brecciated appearance of collapsed overburden.

Plate 5.1 a through d. Views of Knobloch clinker outcrops.

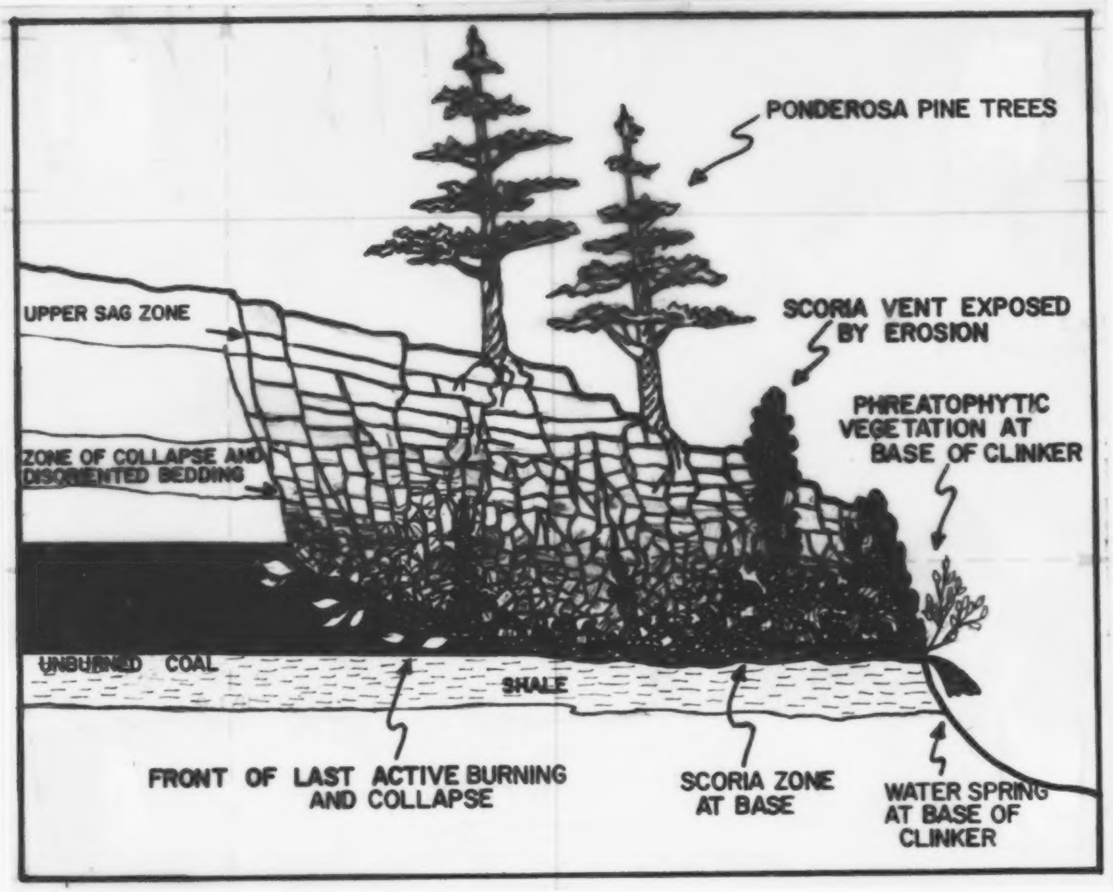

PONDEROSA PINE TREES
UPPER SAG ZONE
SCORIA VENT EXPOSED BY EROSION
PHREATOPHYTIC VEGETATION AT BASE OF CLINKER
ZONE OF COLLAPSE AND DISORIENTED BEDDING
UNBURNED COAL
SHALE
FRONT OF LAST ACTIVE BURNING AND COLLAPSE
SCORIA ZONE AT BASE
WATER SPRING AT BASE OF CLINKER

Figure 5.22. The structure of clinker.

3) erosion and exposure of coal behind the protective terrace of clinker, perhaps by means of a gully cutting through a clinkered zone into an unburned area; and

4) burning of the coal behind the previously formed clinker to develop a second clinker.

This episodic nature of burning may have been the mechanism by which an number of curious depressions we have termed "clinker basins" were produced, in areas where very thick coal seams (greater than 10 m (33 ft)) burned. The basins are most apparent on the clinker plateau formed by the burning of the Anderson coal seam on the divide between Lame Deer and the Tongue River, and they occur less commonly in the Knobloch burn just west of the Tongue River.

These bowl-shaped depressions range from 0.5 to approximately 2.0 km^2 (0.2 to 0.8 mi^2) in area and are from 10 to 40 m (30 to 130 ft) deep. In some

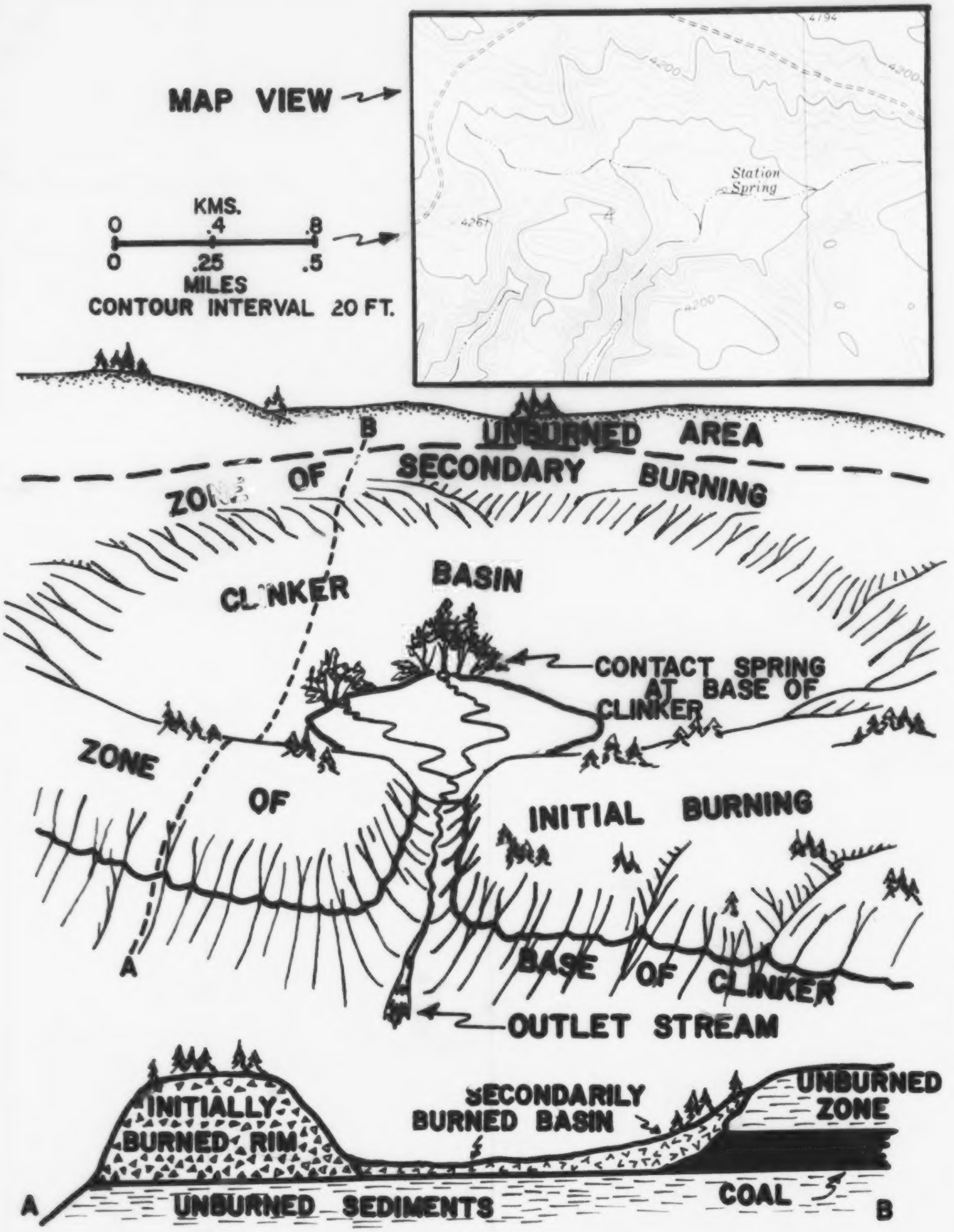

MAP VIEW
KMS.
0
.4
.8
0
.25
.5
MILES
CONTOUR INTERVAL 20 FT.
4794
4200
4200
Station Spring
4261
4200
B
UNBURNED AREA
ZONE OF SECONDARY BURNING
CLINKER BASIN
CONTACT SPRING AT BASE OF CLINKER
ZONE OF INITIAL BURNING
A
BASE OF CLINKER
OUTLET STREAM
INITIALLY BURNED RIM
SECONDARILY BURNED BASIN
UNBURNED ZONE
COAL
A
UNBURNED SEDIMENTS
B

Figure 5.23. Typical clinker basins formed by burning of the Anderson coal.

cases the basins have no outlet, drainage being toward the center of the basin where small ponds may stand during the rainy season, most likely the result of the partial sealing of the bottom of the depression by less permeable soil material. However, in most cases the basin has an hourglass shape, consisting of a bowl breached by a narrow outlet valley. Large springs commonly occur near the location in the basin where the outlet stream has cut down to the contact between the base of the clinker and the less permeable strata below it (Figure 5.23). The two most notable springs of this kind are Crazy Head Springs and Station Springs, both in the Fisher Butte 7.5 minute topographic map quadrangle. Crazy Head Springs has the largest discharge of any spring measured on the Reservation, at 349 liters/min (92 gal/min).

It is our hypothesis that periodic burning, wind and stream erosion, and a difference in rates of erosion between burned and unburned strata, all combine to create clinker basins. Two possible processes are outlined.

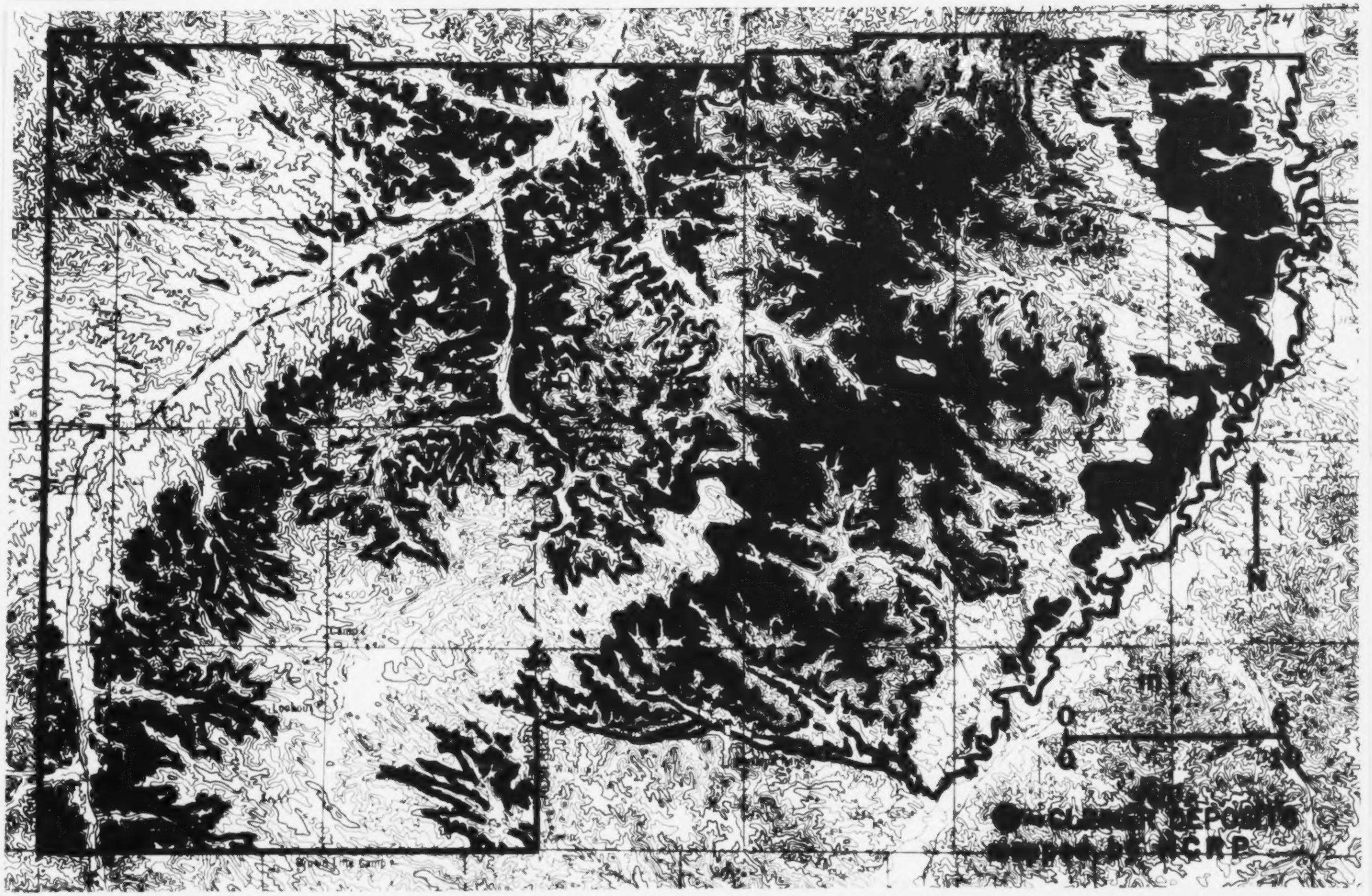
The first hypothesis is: a stream eroding headward into a coal-bearing plateau rimmed by clinker may find narrow avenues of fracture in the clinker which are more easily eroded. The stream works its way along these avenues, carving a narrow valley through the clinker terrace, until the stream reaches the unburned area behind the clinker. There, the stream erodes the overburden more easily than in the clinkered area and is able to form a broad basin. Eventually the stream cuts down into the unburned coal behind the clinker, the exposed coal ignites, and burns to form a second clinker in the floor of the basin and back into the interior of the plateau.

The second hypothesis is: wind erosion may sculpt depressions in plateaus of poorly-consolidated sedimentary rock rimmed by terraces of baked, cemented clinker. The softer, unburned strata is worn away more quickly than the harder, clinkered rock, forming depressions behind the clinker terraces. If enough overburden is blown away, additional coal is exposed, ignites, and forms a second burn extending outward from the center of the depression.

Extent

Coal seams in the Tongue River Member have burned extensively over the Reservation. The appearance of the burns varies from localized oxidation to smut and reddish discoloration in the top few meters of some of the thinner coal seams, to plateaus which are capped by massive clinkers, many kilometers in extent, formed where thick coal seams have burned. Approximately 31 percent of the land surface is covered by clinker (Figure 5.24).

The thickest clinker (up to 70 m (230 ft)) is formed by the burning of the Anderson coal seam and forms an extensive timbered plateau 190 km^2 (73 mi^2) in extent on the eastern half of the Reservation. This is 11 percent of the total Reservation land surface. The Knobloch coal forms the next largest clinker zone in the eastern half of the Ashland Benchland, capping the bluffs above the Tongue River. The Wall and Canyon coals combine to form a very thick clinker along the sides of the Rosebud Creek Valley near Kirby in the southwestern part of the Reservation. Many other areas are significantly burned.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CLINKER DEPOSITS
MAPPED BY NCRP

Figure 5.24. Clinker deposits of the Northern Cheyenne Reservation, Montana.

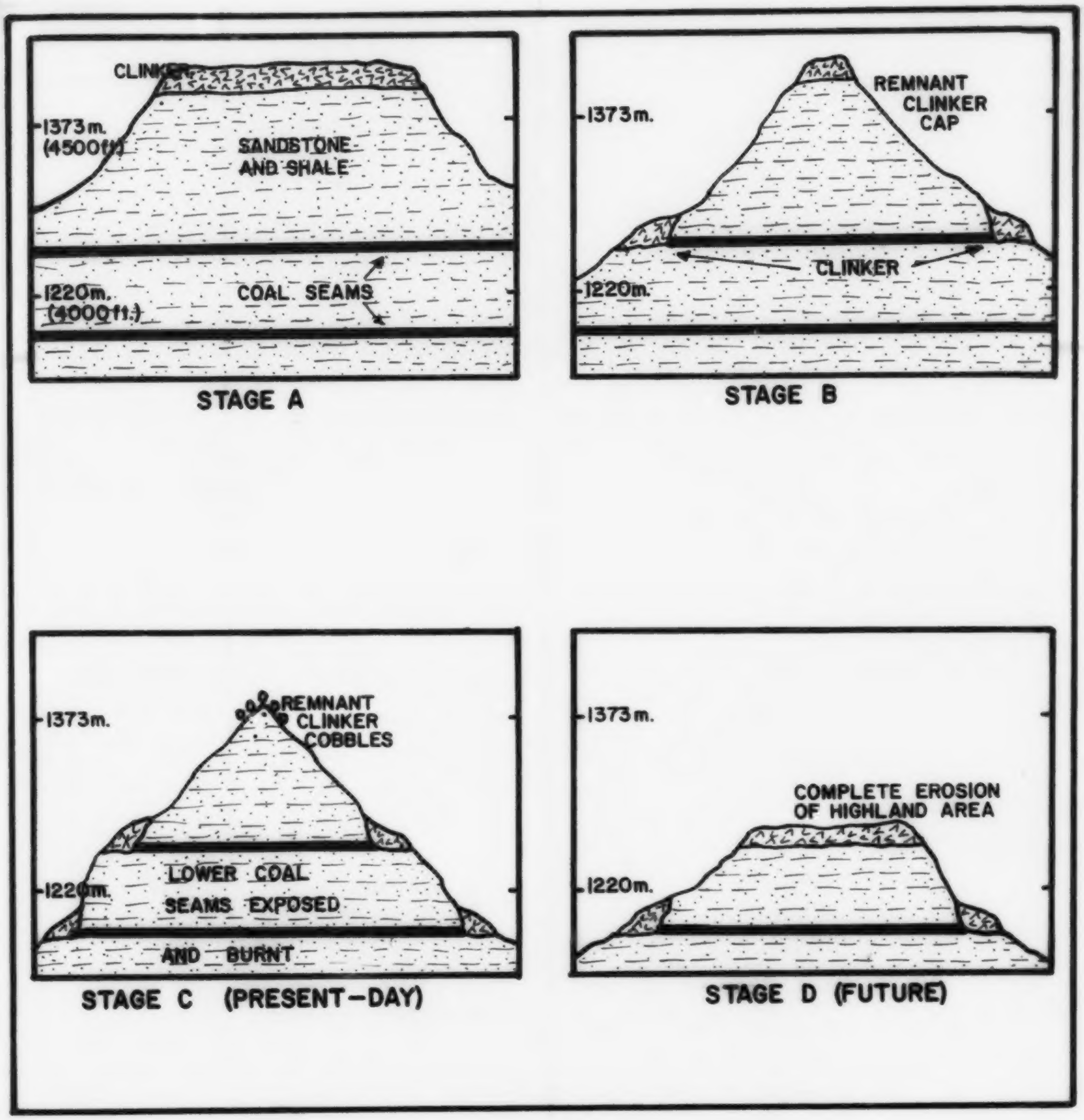

CLINKER
1373 m.
(4500 ft.)
SANDSTONE AND SHALE
1220 m.
(4000 ft.)
COAL SEAMS
STAGE A
REMNANT CLINKER CAP
1373 m.
CLINKER
1220 m.
STAGE B
1373 m.
REMNANT CLINKER COBBLES
1220 m.
LOWER COAL SEAMS EXPOSED AND BURNT
STAGE C (PRESENT-DAY)
1373 m.
COMPLETE EROSION OF HIGHLAND AREA
1220 m.
STAGE D (FUTURE)

Figure 5.25. Development of Topography, Little Wolf Highlands, Northern Cheyenne Reservation.

Coal seams tend to burn more heavily on the south-facing sides of hills where there is more exposure to sun and less tree cover than on the shadier northern slopes. Burns are more extensive on exposed hills and promontories than in areas where erosion has been rapid and the coal has not had time to slacken sufficiently to burn.

Age

Clinker formation on the Reservation is postulated to have occurred in the Quaternary Period within the last two million years. The first clinkers were probably formed as downcutting river systems exposed the coals of the Wasatch and topmost Fort Union Formations. As the Tongue River cut deeper, lower-lying seams in the Fort Union, such as the Anderson and then Knobloch, were exposed and burned. Meanwhile, as river valleys widened, tributary streams continued cutting further back into the highlands. Clinker was slowly eroded away from the outer edges of benches, and more coal was exposed and burned. This burning/erosion/burning cycle occurred throughout the Quaternary up to the present. A figure showing topographic development of the Little Wolf Highland in the northwestern corner of the Reservation illustrates this process (Figure 5.25).

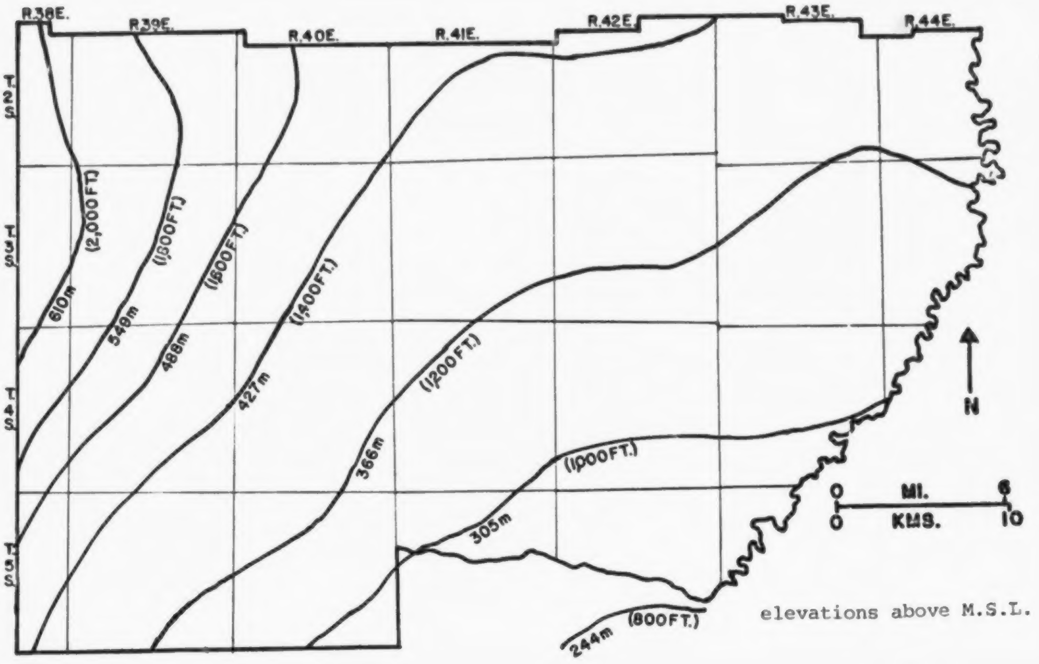
Preliminary radiometric dates of clinker deposits in the Powder River Basin have been obtained by Dr. Donald A. Coates of the USGS in Denver, Colorado. Preliminary studies suggest a mid-Pleistocene age for the Anderson-Wyodak burn in the Rochelle Hills southeast of Reno Junction in Wyoming. Other evidence suggests that clinkers have been forming for a considerable time, because clinker occurs in stream terrace gravels up to 340 m (1,100 ft) above the Yellowstone River in the Forsyth coal field (Dobbin, 1929). However, gravels on the Powder River - Tongue River Divide to the east of the Reservation are reported by Bass (1932) to be cemented in a clinker, indicating that the gravels are older than that particular clinker. Moreover, lag gravels in the high country of the Reservation lack clinker cobbles. These data suggest that further work on the relationship between clinkers and gravel terraces in southeastern Montana may help tie down the geomorphic history of the region.

STRUCTURE

The Reservation lies on the northwestern limb of the Powder River Basin. Strata lie nearly horizontal, but are offset by minor normal faults.

Figure 5.26 shows a map of the structure at the top of the Upper Cretaceous Bearpaw Shale on the Reservation (after Lewis and Roberts, 1978). A gentle southeasterly dip is observed, with the steepest dip at approximately one degree to the southeast in the extreme western part of the Reservation. To the east, near the axis of the Tongue River Syncline, the dip flattens out, and becomes more southerly where a broad syncline plunges south-southeastward from the vicinity of Lame Deer toward Birney. The southwestern limb of the Ashland Syncline is present in the extreme north of the Reservation west of

Lame Deer. The general structural pattern at the base of the Tongue River Member is similar, although higher above mean sea level. Elevations at the base of the Tongue River Member range from a low of 730 m (2,400 ft) in the southeast part of the Reservation to 850 m (2,800 ft) in the northeast corner, and to a maximum of 1,070 m (3,500 ft) along the western edge.



elevations above M.S.L.

Figure 5.26. Structure at the top of the Bearpaw Shale, Northern Cheyenne Reservation (after Lewis and Roberts, 1977).

Figure 5.27 presents surface structural features observed during field work as well as through drill data and aerial photo interpretation by Project staff. So far, normal faulting with up to 50 m (160 ft) of displacement has been found. Most of the lineaments and fault zones trend N 70°E. These faults may be eastward extensions of the normal en echelon faults trending northeast to east which characterize the Lake Basin Wrench Fault Zone to the west of the Reservation, or may be expressions of regional strike-slip deformation between the Lake Basin Zone and the Nye-Bowler Fault Zone near the Montana - Wyoming border south of the Reservation. Prominent N.70°E alignment is observed along the upper reaches of both forks of Muddy Creek as well as Rosebud Creek northeast of Busby. The alignment of many streams in a northwest - southeast direction, such as in the southern part of T4S R40E, is probably due to geomorphic influences rather than faults, although a few faults and joints have been observed trending in that direction. The Tongue River Valley appears relatively free from faults, compared to the northwest and south-central parts of the Reservation, where the most faulting has been observed. Local dips of up to seven degrees near fault zones have been found. Strike-slip components of faulting may be present but not as obvious due to the nearly horizontal attitude of the strata.

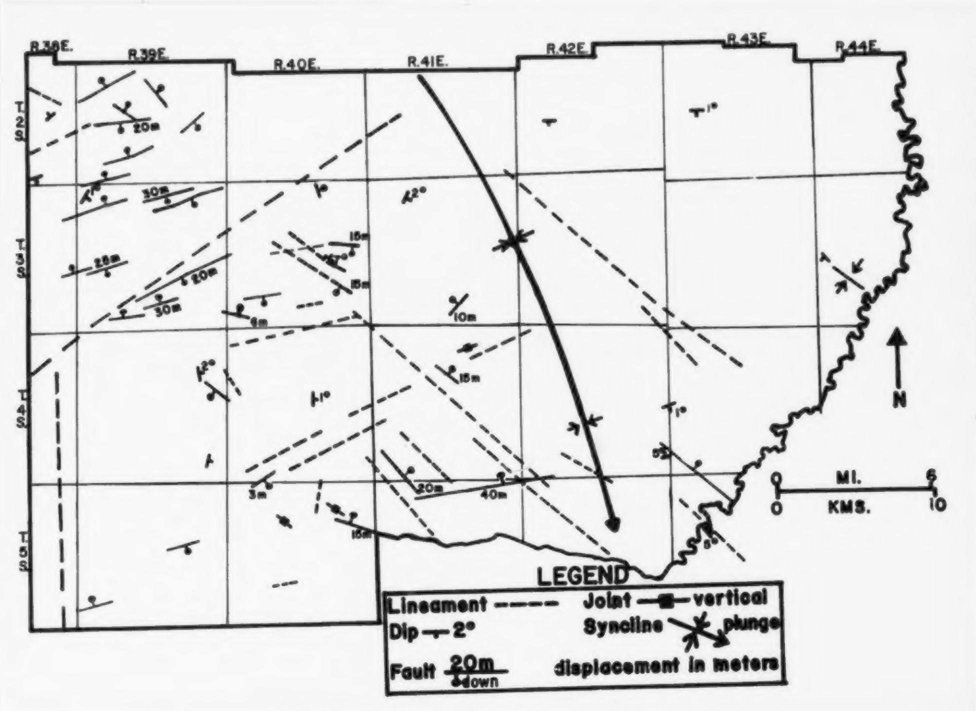


Figure 5.27. Map of surface structural features, Northern Cheyenne Reservation, Montana.

One zone of interest was noticed in the northern part of the Buffalo Jump Priority Study Area (northeast quarter of Sec.10 T4S R41E), where a wall of limy, cross-bedded, medium-grained sandstone two to five meters (five to fifteen feet) high strikes N70°E across the landscape. The bedding is nearly horizontal. The wall seems to have been created by a northeast-trending joint system, along which a calcium-rich solution percolated upwards and indurated the strata along the joint, thus providing more resistance to erosion than surrounding strata. The direction of jointing lines up well with the northeast lineaments of the upper reaches of Muddy Creek.

The dip near clinkered zones is strongly deformed due to the clinkers' collapse into voids left by the burned coal. Penecontemporaneous growth faulting toward the seaward edge of the Paleocene delta systems may also have caused small displacements in Paleocene strata.

The valley of Rosebud Creek near Kirby parallels the northerly trend of the western face of the Wolf Mountains, and may indicate north-trending jointing. However, in the Kirby area of the Reservation, displacement due to faulting in a northerly direction has not been observed.

Structure does not appear to control groundwater movement within the Tongue River Member on a regional basis as much as stratigraphy does, because of the very diverse permeabilities and the limited lateral extent (except for the continuous coal beds) of different rock units within this Member. However, faults and folds may have local influence on the location of springs and on flow patterns. Rock finely ground up in a fault zone can serve as a barrier to groundwater movement, or conversely, fractures caused by jointing and faulting can serve as conduits to transmit water. The absence of hydrogeologic data adjacent to mapped faults precluded the definition of the effect of minor faulting on the near surface groundwater system. More detailed drilling and hydrologic field work are necessary to delineate the exact role of structure in the hydrogeologic system.

GEOLOGY OF PRIORITY STUDY AREAS

INTRODUCTION

The Logging Creek, Buffalo Jump, and Indian Coulee Priority Study Areas were selected for detailed geologic and hydrologic study after the first year of geologic field work. Each site was representative of typical hydrogeologic regimes found on the Reservation and within the region. Detailed drilling, coring, field mapping, and aerial photo interpretation were performed to characterize the geologic framework of each area. These descriptions were then used to delineate the surface water and groundwater systems operating in each area, and the potential impacts to the area from coal strip mining. A description of the sites and related geology follows.

LOGGING CREEK PRIORITY STUDY AREA

The Logging Creek site lies west of Ashland, Montana. It is bordered on the east by the Tongue River, and on the west by a prominent north-south ridge running the length of the Reservation (Figure 5.28).

The area is of moderately low relief, consisting of a broad plateau (the Ashland Benchland) dissected by numerous small coulees draining eastward into the alluvial lowland of the Tongue River (Plate 5.2). The Benchland lies 70 to 100 m (230 to 330 ft) above the present level of the Tongue River near Ashland and decreases in prominence south towards Birney Day Village. The Benchland is about ten kilometers (six miles) wide west of Ashland, but decreases to about four kilometers (two and a half miles) wide south of Birney Day. Elevations range from 910 to 1,040 m (3,000 to 3,400 ft) above mean sea level. One perennial stream, Logging Creek, and numerous other ephemeral streams are present. Stebbins Creek, near the northern boundary of the area, flows during most of the year to a point just above its confluence with the dry Lake Creek drainage. Downstream from that point the drainage is dry most of the year.

Cattle grazing is the dominant land use in the area. The eastern portion

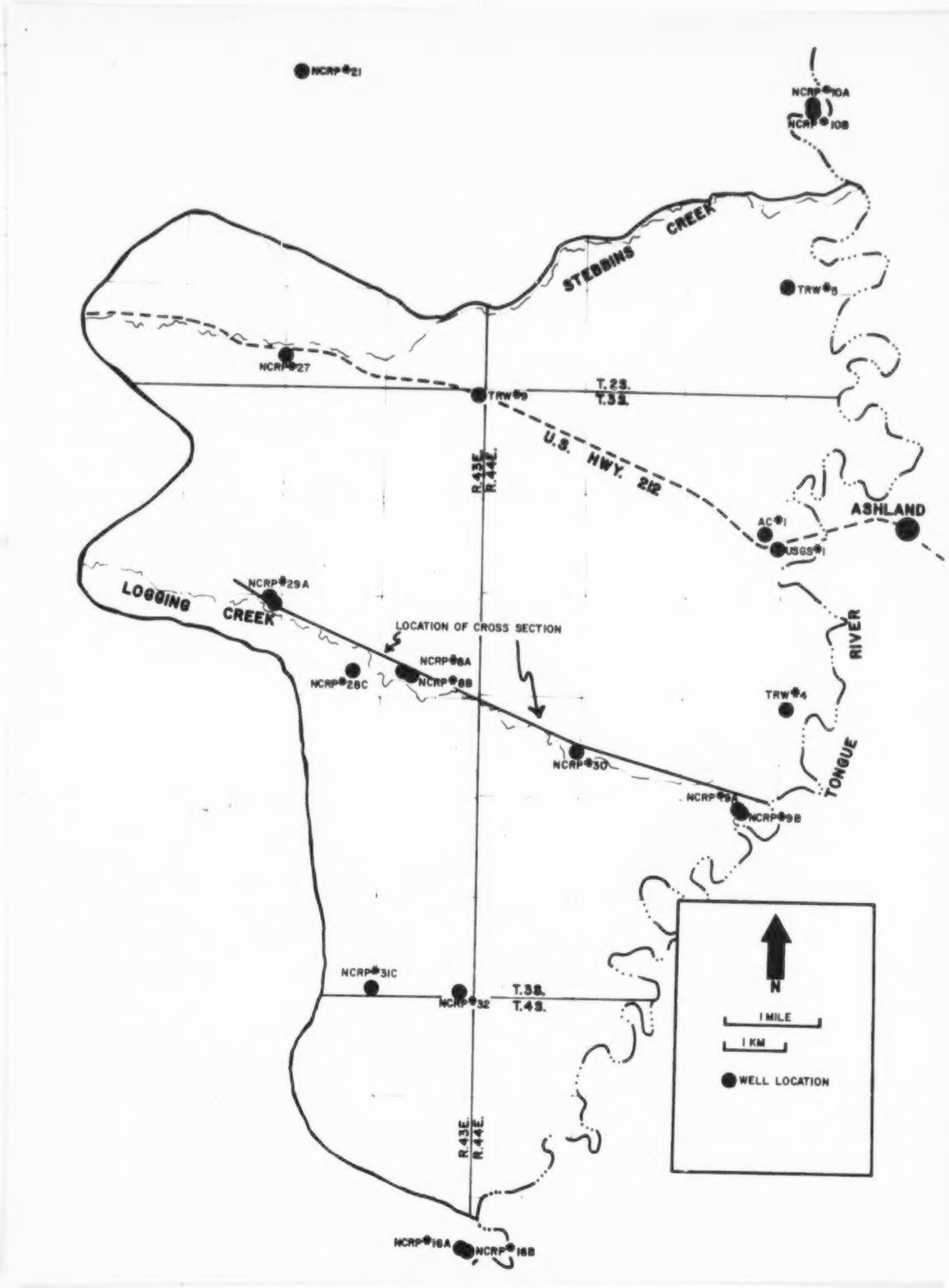

NCRP #21
NCRP #10A
NCRP #10B
STEBBINS CREEK
TRW #5
NCRP #27
TRW #9
T.2S.
T.3S.
U.S. HWY. 212
R.43E.
R.44E.
ASHLAND
AC #1
USGS #1
NCRP #29A
LOGGING CREEK
LOCATION OF CROSS SECTION
NCRP #8A
NCRP #8B
NCRP #28C
RIVER
TRW #4
TONGUE
NCRP #30
NCRP #9A
NCRP #9B
N
1 MILE
1 KM
WELL LOCATION
NCRP #31C
NCRP #32
T.3S.
T.4S.
R.43E.
R.44E.
NCRP #16A
NCRP #16B

Figure 5.28. Logging Creek Priority Study Area wells and cross-section locations.

Plate 5.2 View of Logging Creek Priority Study Area. Tongue River in foreground, Logging Creek and bare hills of priority area in middle distance, Divide Clinker Plateau on horizon.

contains some stands of ponderosa pine on the clinkered areas. Crops are raised in the Tongue River Valley, and a small amount of wheat on the Benchland. The availability of water from the Tongue River makes the Logging Creek area a potential location for irrigation. The area also is being considered for the location of rural housing because U.S. Highway 212 and the town of Ashland are nearby.

The geologic units exposed in the study area are the sediments of the Tongue River Member, associated clinker, and Quaternary alluvium and terrace gravels (Figure 5.29). Geologic data included lithologic logs of 21 groundwater monitoring wells, 15 of which were drilled by the Project (two of which had continuous cores taken).

Most of the surface exposure of the Tongue River Member in the study area lies between the Knobloch and Pawnee coal seams. The shalier upper part of this interval forms badlands along the base of the slopes of the East Divide Transition Zone. The lithology shown in NCRP core hole 28C (Figure 5.30 and Appendix Figure A-8) is representative of the lower 37 m (120 ft) of this interval

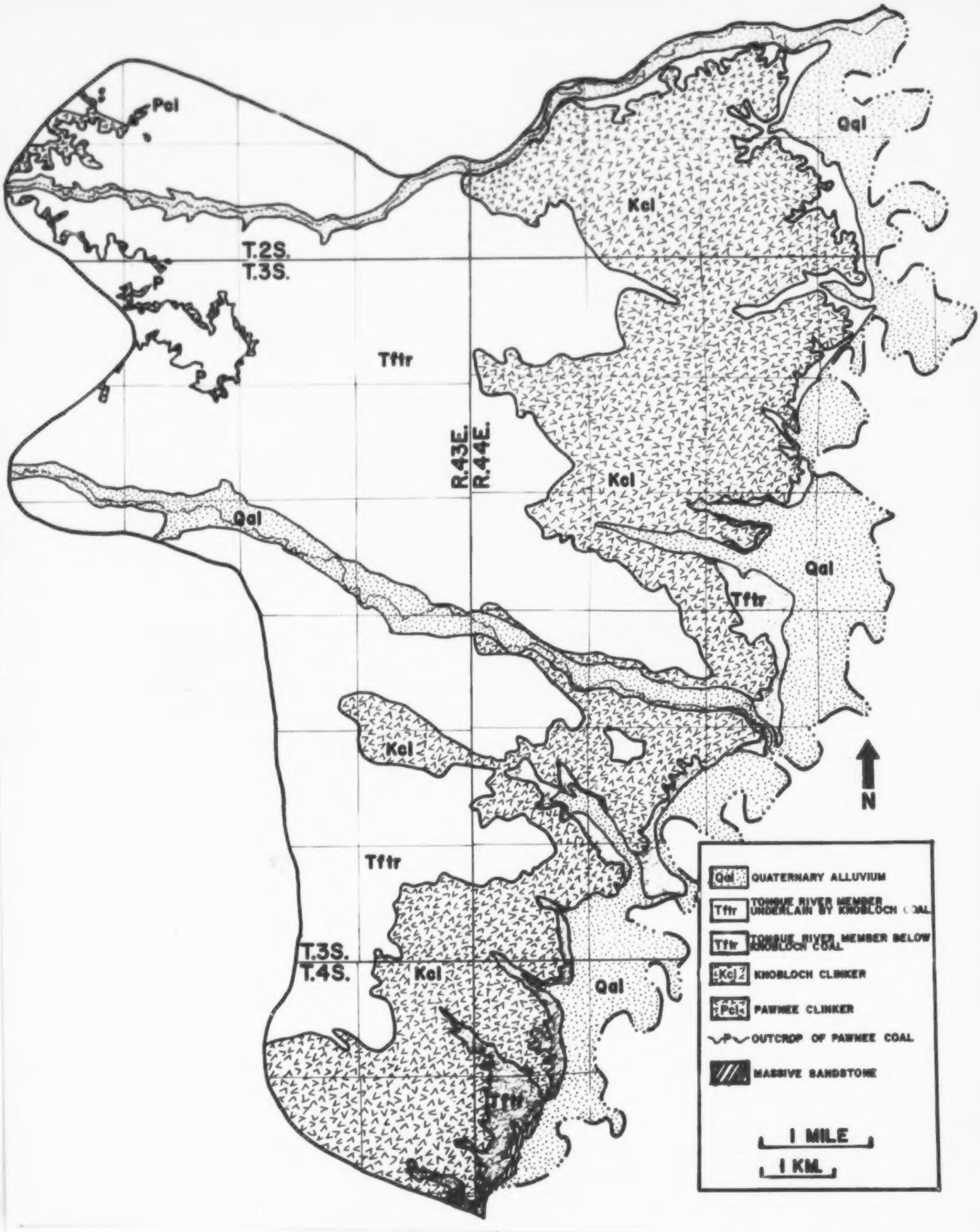

Pcl
P
T.2S.
T.3S.
Tftr
R.43E.
R.44E.
Qal
Kcl
Qal
Kcl
Qal
Tftr
Kcl
Tftr
T.3S.
T.4S.
Kcl
Qal
Tftr
N
Qal QUATERNARY ALLUVIUM
Tftr TONGUE RIVER MEMBER UNDERLAIN BY KNOBLOCH COAL
Tftr TONGUE RIVER MEMBER BELOW KNOBLOCH COAL
Kcl KNOBLOCH CLINKER
Pcl PAWNEE CLINKER
P OUTCROP OF PAWNEE COAL
MASSIVE SANDSTONE
1 MILE
1 KM.

Figure 5.29. Geologic map of Logging Creek Priority Study Area.

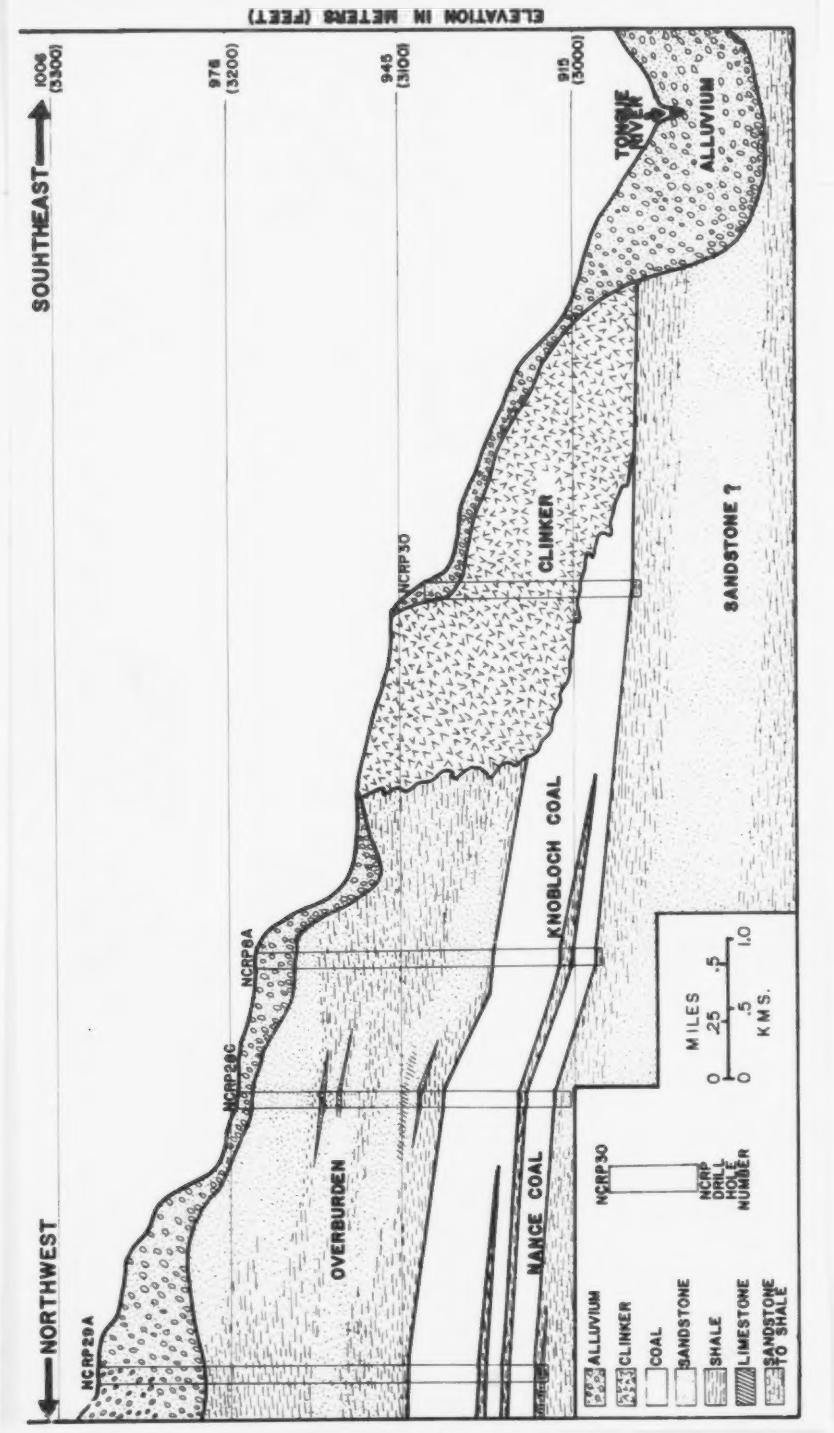

ELEVATION IN METERS (FEET)
1006 (3300)
976 (3200)
945 (3100)
915 (3000)
NORTHWEST
SOUTHEAST
NCRP29A
NCRP29C
NCRP28A
NCRP30
OVERBURDEN
NANCE COAL
KNOBLOCH COAL
CLINKER
SANDSTONE ?
ALLUVIUM
TONGUE RIVER
ALLUVIUM
CLINKER
COAL
SANDSTONE
SHALE
LIMESTONE
SANDSTONE TO SHALE
NCRP30
NCRP DRILL HOLE NUMBER
MILES
0 .25 .5 1.0
0 .5 1
KMS.

Figure 5.30. Geologic cross-section along Logging Creek.

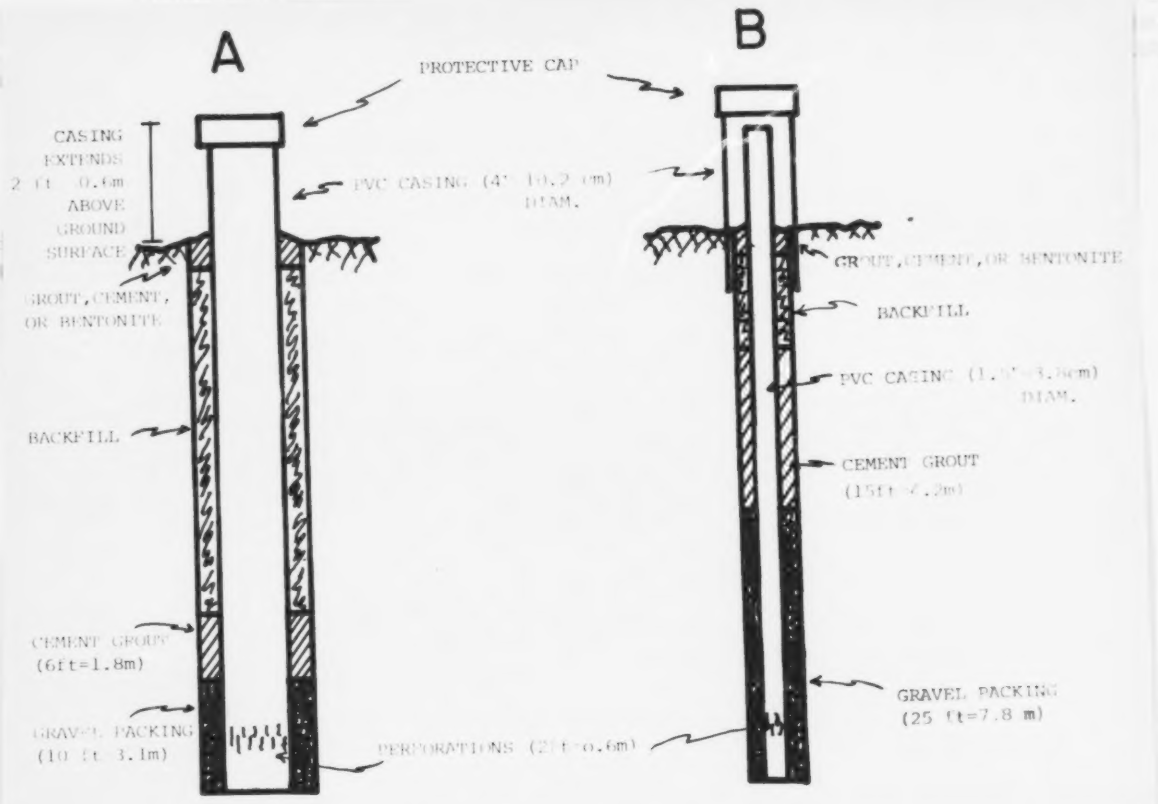

A
B
PROTECTIVE CAP
CASING EXTENDS 2 ft 0.6m ABOVE GROUND SURFACE
PVC CASING (4" 10.2 cm) DIAM.
GROUT, CEMENT, OR BENTONITE
BACKFILL
CEMENT GROUT (6ft=1.8m)
GRAVEL PACKING (10 ft 3.1m)
PERFORATIONS (2 ft 0.6m)
GROUT, CEMENT, OR BENTONITE
BACKFILL
PVC CASING (1.5"=3.8cm) DIAM.
CEMENT GROUT (15ft 4.2m)
GRAVEL PACKING (25 ft=7.8 m)

Figure 6.2. Monitoring Well Design.

REGIONAL HYDROGEOLOGY

OCCURENCE AND QUALITY

Six hydrostratigrpahic units, which are separated by less permeable material, have been identified in southeastern Montana. A description by unit of the Unconsolidated, Tongue River, Tullock-Hell Creek, Lakota Sandstone, Madison, and Red River Units are discussed briefly to provide data on the regional hydrogeologic setting. Figure 5.5 presents a regional geologic map which shows where these units are exposed at the surface.

Unconsolidated Unit

The Unconsolidated Unit is Quaternary in age and is found bordering and underlying the major stream systems of the region. It is composed of clay, silt, sand, and gravel deposits. A majority of the wells near streams are finished in the Unconsolidated Unit. Well yields range from 37.9 to 2,653 lpm (liters per minute) or 10 to 700 gpm (gallons per minute). Total dissolved solids range from 500 mg/l (milligrams per liter) to several thousands milligrams per liter. The principal ions are sodium, calcium, magnesium, bicarbonate, and sulfate. This unit is an important regional source for immediately above the Knobloch coal seam. Here the overburden is primarily fine sandstone and minor sandy shale, with thin calcareous lenses. Immediately above the Knobloch seam is a 5 m (15 ft) thick shaly zone. The Knobloch itself is split into an upper bench 13.4 m (44 ft) thick and a lower bench 5.2 m (17 ft) thick separated by 1.2 m (4 ft) of calcareous sandstone and shale. The underburden just below the lower bench is sandy to shaly.

South of Logging Creek the lower bench splits off further from the main Knobloch to form the Nance seam. To the west two lower benches split off from the main Knobloch. Between Logging Creek and Stebbins Creek in R44E, all benches merge to form a single seam over 18 m (60 ft) thick. North of Stebbins Creek, however, the Sawyer seam sharply splits off from the main Knobloch and both seams thin.

In the Tongue River Valley, the Knobloch coal ranges from 9 to 28 m (30 to 65 ft) in thickness. This is the major strippable coal . Resistant clinker beds cap the bluffs along the west side of the Tongue River. These clinkers were formed by the burning of Knobloch coal. Locally they exceed 46 m (150 ft) in thickness. The Knobloch has burned westward as much as three kilometers (two miles) into the eastern half of the benchland. This resistant border of clinker is keeping the unburned part of the Ashland Benchland behind the clinker from rapidly eroding into the Tongue River. In some areas, such as NCRP 30 in the Logging Creek Valley, the Knobloch is only partially burned, and unburned coal remains below the present water table.

Pockmarked cliffs and knobs of massive sandstone are exposed at the 910 m (3,000 ft) level below the Knobloch clinker in the southwest quarter of Sec. 7 T4S R44E. In one location, the Tongue River itself is cutting into a cliff of this sandstone.

Most of the strata are nearly flat-lying or gently warped with minimal faulting. The base of the Knobloch clinker in the Tongue River Valley is bowed down to 906 m (2,970 ft) in the northwest quarter of Sec.28 T3S R44E. The base of the clinker rises to 933 m (3,060 ft) toward the north end of the priority area, and to 946 m (3,100 ft) toward the south end, forming a gentle syncline whose axis intersects the Tongue River just south of Logging Creek. A spring comes out from the base of the clinker at the approximate location of the axis.

BUFFALO JUMP PRIORITY STUDY AREA

The Buffalo Jump site is located in the interior part of the Reservation to the south of Lame Deer (Figure 5.31). The area is covered with stands of timber and is currently used primarily for cattle grazing. The area is at the head of five drainages feeding Rosebud Creek to the north and the Tongue River to the south, including spring-fed Cow Creek and Paddy Creek to the northwest, the south fork of Lame Deer Creek to the north, and Clubfoot Creek and Black Eagle Creek to the southeast.

The higher elevations of the Buffalo Jump Priority Study Area lie within

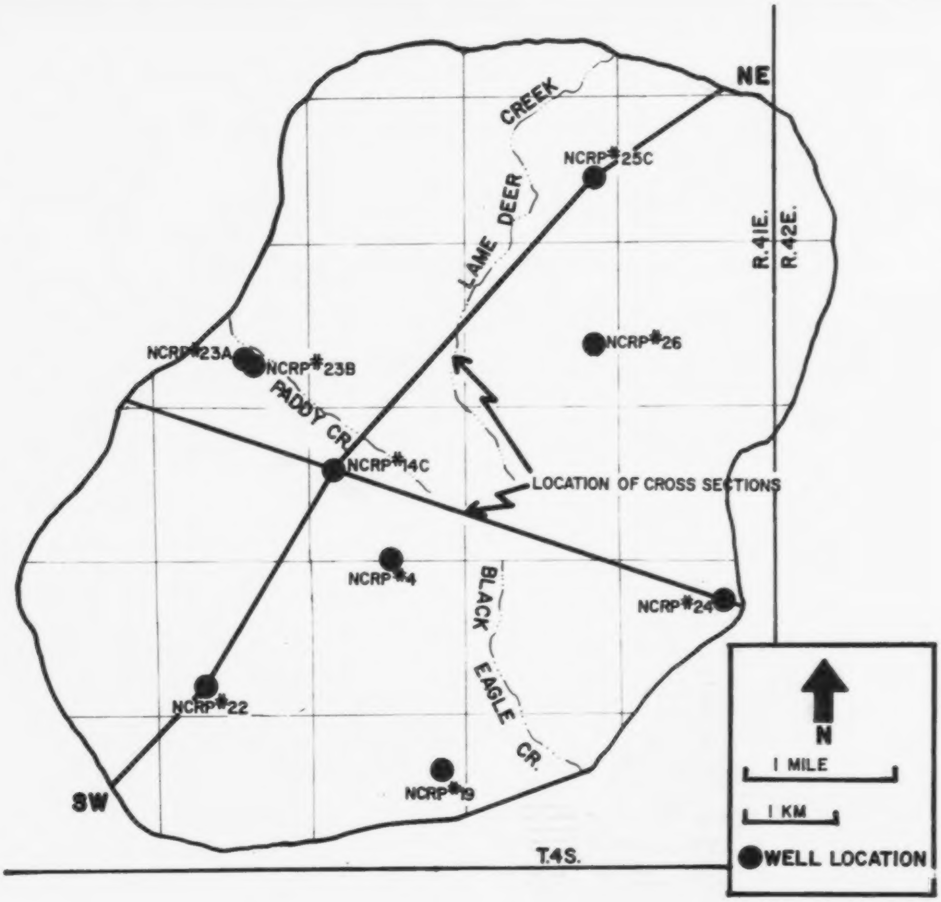

NE
SW
CREEK
LAME DEER
NCRP#25C
R.41E.
R.42E.
NCRP#23A
NCRP#23B
NCRP#26
PADDY CR.
NCRP#14C
LOCATION OF CROSS SECTIONS
NCRP#4
BLACK EAGLE CR.
NCRP#24
NCRP#22
NCRP#19
N
1 MILE
1 KM
WELL LOCATION
T.4S.

Figure 5.31. Buffalo Jump Priority Study Area wells and cross-section locations.

the rolling topography of the Divide Highland and Divide Clinker Plateau physiographic provinces (Plate 5.3). The Anderson clinker forms a resistant border below which the topography is characterized by the rough terrain and steep-walled canyons of the Transition Zones. Elevations range from 1,180 m (3,860 ft) at the base of Black Eagle Creek to 1,350 m (4,440 ft) on a few of the high hills in the central part of the study area. The Buffalo Jump, a picturesque archaeological site, is located in the southwestern corner of the study area.

Geological data were obtained through the construction of nine Project wells, two of which were continuously cored. Geologically, the study area

Plate 5.3 View of Buffalo Jump Priority Study Area, looking southeast. (High surface of Wasatch Formation in foreground; extensive plateau surface formed by the burning of the Anderson coal seam and dissected by Black Eagle Fork of Cook Creek in middle distance; Tongue River Valley on horizon.

is a block of land overlying the Anderson coal seam. Contrasting with the Logging Creek site, the Buffalo Jump area is essentially a "strippable island" where the Anderson seam is burned throughout its outcrop, but has been preserved in the central portion of the study area. The base of the Anderson seam is generally 1,210 to 1,240 m (3,970 to 4,080 ft) above MSL, with highest elevations in the northwest, and its exposures are burned along all of the drainages emanating from this area (Figure 5.32).

In the interior part of the study area, where elevations exceed 1,340 m (4,400 ft), the Anderson seam is too deep for surface mining by present definitions and/or technology. A higher seam, the Roland, which was measured at 4 m (12 ft) thick in NCRP 4, could be strip mined in parts of the high country.

In the Buffalo Jump Priority Study Area, the Anderson seam is thinnest in the west, where a thickness of 13 m (42 ft) was measured in NCRP 22. Eastward, the Anderson thickens as upper benches join the main seam. At NCRP 25C, 20 m (64 ft) of continuous coal was cored, plus 1.2 m (4 ft) of coal separated by partings and a lower bench 2.4 m (8 ft) thick 6 m (20 ft) below

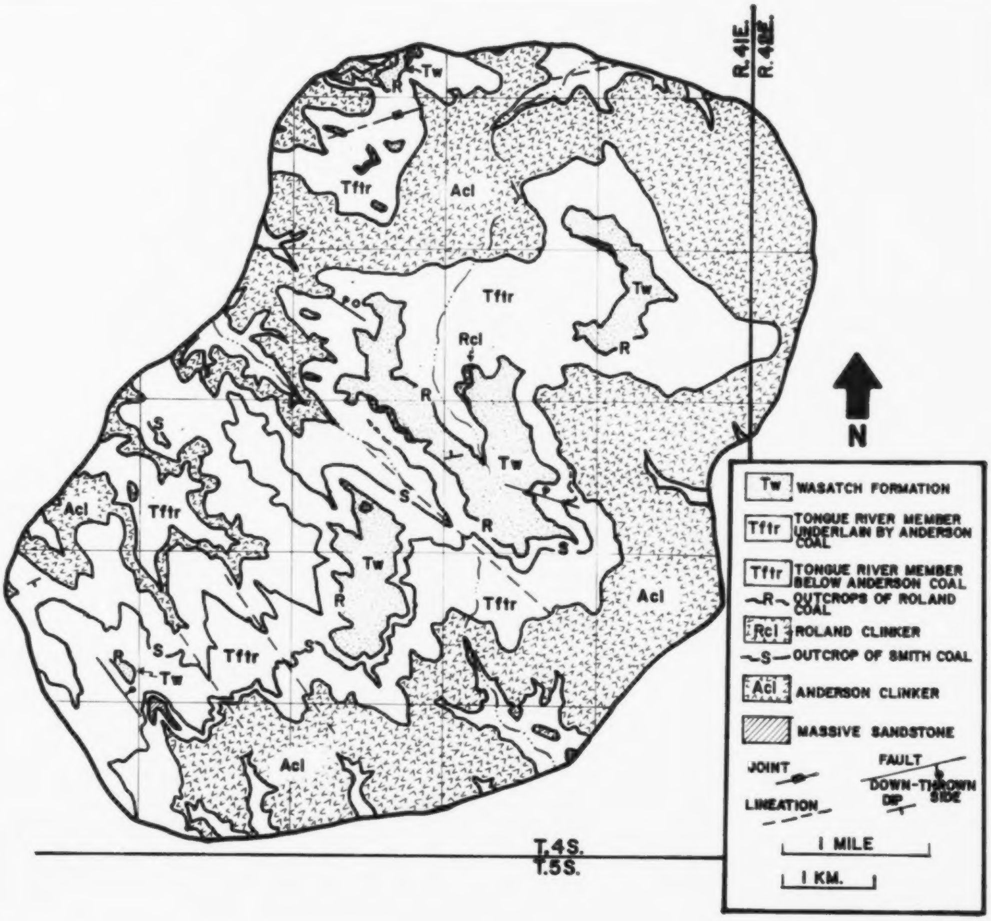

R.41E.
R.42E.
Tw
Tftr
Acl
Rcl
R
S
N
T.4S.
T.5S.
Tw WASATCH FORMATION
Tftr TONGUE RIVER MEMBER UNDERLAIN BY ANDERSON COAL
Tftr TONGUE RIVER MEMBER BELOW ANDERSON COAL
R OUTCROPS OF ROLAND COAL
Rcl ROLAND CLINKER
S OUTCROP OF SMITH COAL
Acl ANDERSON CLINKER
MASSIVE SANDSTONE
JOINT
FAULT
DOWN-THROWN SIDE
DIP
LINEATION
1 MILE
1 KM.

Figure 5.32. Geologic map of Buffalo Jump Priority Study Area.

the main Anderson. This lower bench lies underneath the main Anderson coal throughout the study area. A cross-section is presented in Figure 5.33 and a lithologic log in Appendix Figure A-9.

East and north of NCRP 25C, the Anderson has burned completely. The Anderson clinker wraps around to the south to form an extensive burn in the southern and eastern parts of the study area, and extends northeastward across the Reservation to form the Divide Clinker Plateau.

A massive sandstone cliff over 18 m (60 ft) high occurs between the Smith and Anderson coals at the Buffalo Jump in the northwest quarter of Sec.33 T4S

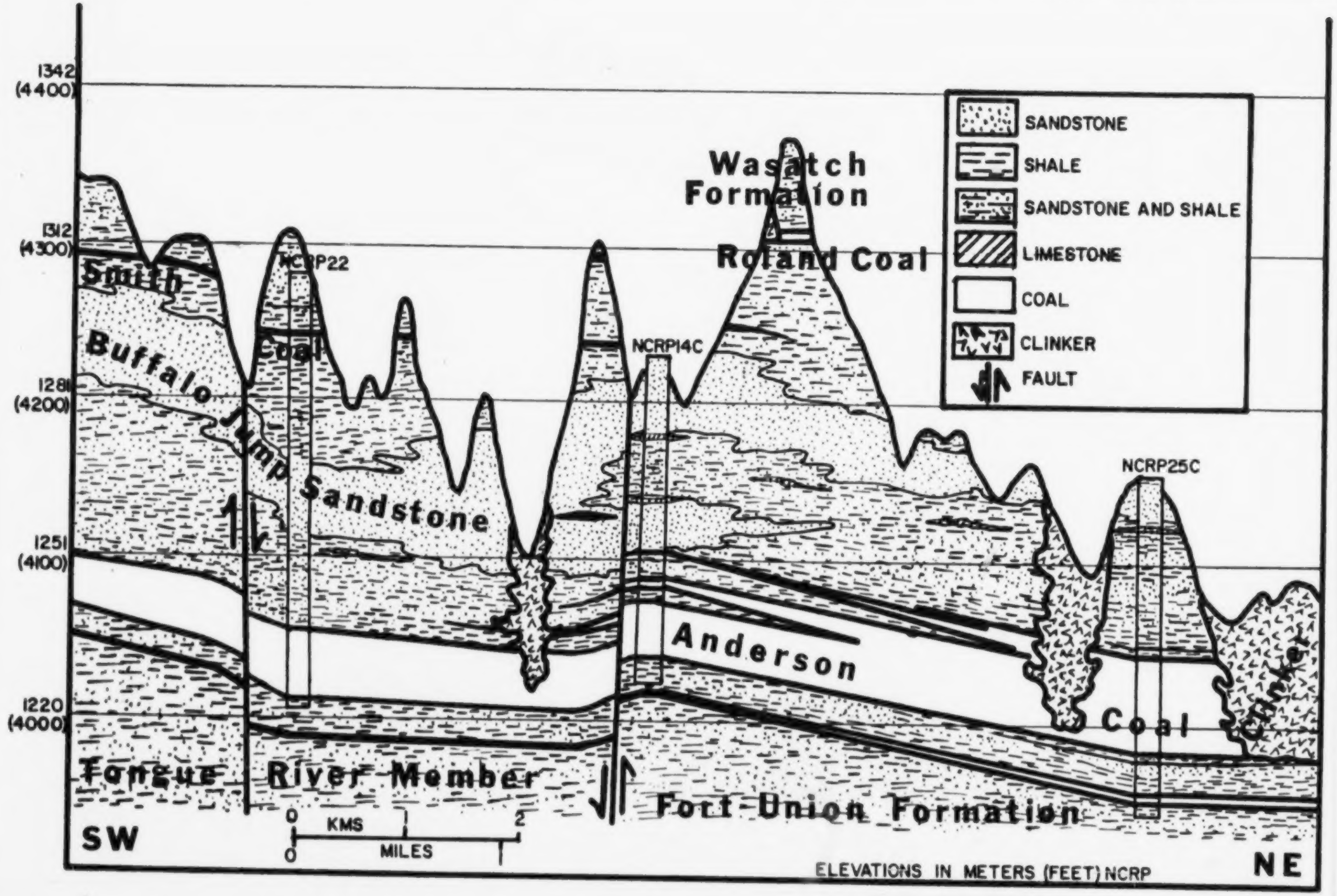

1342 (4400)
1312 (4300)
1281 (4200)
1251 (4100)
1220 (4000)
Wasatch Formation
Roland Coal
Smith
Buffalo Jump Sandstone
Coal
NCRP22
NCRP14C
NCRP25C
Anderson
Coal
Clinker
Tongue River Member
Fort Union Formation
SW
NE
0 KMS 2
0 MILES 1
ELEVATIONS IN METERS (FEET) NCRP
SANDSTONE
SHALE
SANDSTONE AND SHALE
LIMESTONE
COAL
CLINKER
FAULT

Figure 5.33. Geologic cross-section of Buffalo Jump Priority Study Area.

E. This sand unit may be traced in the subsurface to NCRP 14C, and is considered to be a channel sandstone.

The Smith bed is 1.8 m (6 ft) thick in NCRP 4 and about the same in outcrops. It lies 31 to 55 m (100 to 180 ft) above the Anderson coal. The Smith pinches out in the northern half of the study area. Outcrops contain abundant petrified wood.

The Roland bed crops out on the sides of the high hills in the central and northern parts of the study area, where it forms clinker in some areas. In unburned areas, the Roland is about 3 m (10 ft) thick and lies about 21 m (70 ft) above the Smith seam.

Above the Roland seam lies up to 37 m (120 ft) of possible Wasatch Formation, similar in composition to the underlying Tongue River Member of the Fort Union Formation. The highest mesas are capped by the thin-bedded sandstone which exhibits ripple marks in places.

A pronounced northwest-trending lineation of hills and valleys is apparent, especially in the south and west of the study area, and is thought to be geomorphically controlled, with minor jointing and faulting. A joint system trending N70°E in the northern part of the study area has influenced formation of a wall of resistant sandstone and possibly controls the drainage pattern of Lame Deer Creek northeast of the Bixby Ranch. The structure rises irregularly toward the northwestern part of the study area.

INDIAN COULEE PRIORITY STUDY AREA

The Indian Coulee Priority Study Area is situated entirely within the northwestern watershed of Rosebud Creek, between the towns of Busby and Lame Deer (Figure 5.34). The ephemeral drainage of Butte Creek, Indian Coulee, David Creek, and Wood Gulch contain water only during periods of heavy snowmelt and/or rains. Wood Gulch Reservoir, located just east of NCRP 37C, fills up with water only after major storms.

The study area is used mostly for cattle grazing; some dryland grain crops and hay are raised in the Rosebud Creek Valley. The higher elevations also contain some stands of pine timber. The study area ranges in elevation from 990 to 1,210 m (3,250 to 3,980 ft), and can be characterized as a series of gentle southeasterly trending valleys separated by fairly low, near-parallel ridges, as well as a few isolated clinker capped buttes such as Painted Hill. General elevation increases from Rosebud Creek toward the Little Wolf Highlands, which are located to the northwest of the study area. The Indian Coulee Priority Study Area lies within the Busby Upland and Rosebud Creek Alluvial Lowland physiographic provinces (Plate 5.4).

Strata exposed in the Study area lie for the most part within the basal 200 m (660 ft) of the Tongue River Member and are among the oldest strata exposed on the Reservation. The main strippable coal seams have been identified as the Rosebud and McKay for the purpose of this report: however, correlations

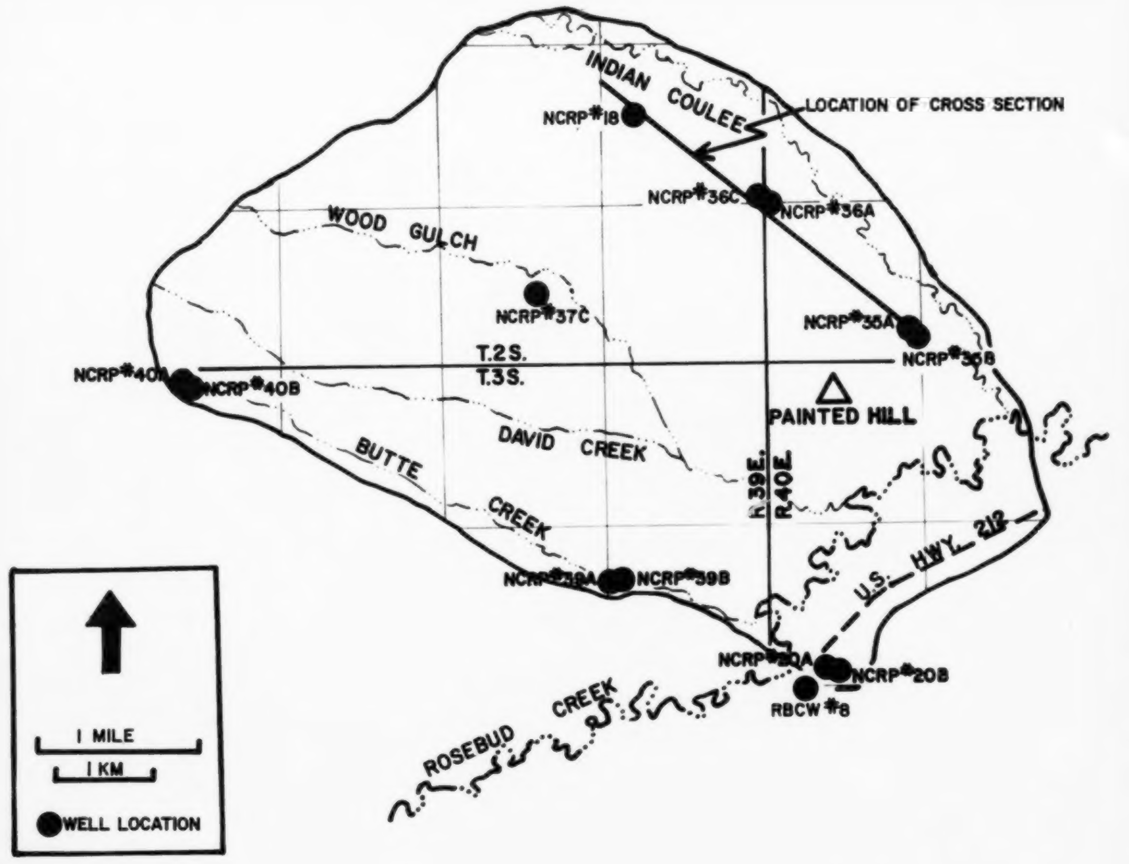

INDIAN COULEE
LOCATION OF CROSS SECTION
NCRP#18
NCRP#36C
NCRP#36A
WOOD GULCH
NCRP#37C
NCRP#35A
NCRP#35B
T.2S.
T.3S.
NCRP#40A
NCRP#40B
PAINTED HILL
DAVID CREEK
BUTTE CREEK
R.39E.
R.40E.
U.S. HWY. 212
NCRP#39A
NCRP#39B
NCRP#20A
NCRP#20B
RBCW#8
ROSEBUD CREEK
1 MILE
1 KM
WELL LOCATION

Figure 5.34. Indian Coulee Priority Study Area wells and cross-section locations.

with the Rosebud and McKay seams mined to the north at Colstrip and Sarpy Creek are tentative at best (Figure 5.35). Geologic data were obtained from 12 wells drilled by the Project, two of which were continuously cored. At NCRP 36A in the eastern part of the study area, the Rosebud-McKay consists of two 3 m (10 ft) thick coal beds separated by 3 m (10 ft) of interburden (Figure 5.36 and Appendix Figure A-10). The McKay coal appears to be about 3 m (10 ft) thick throughout the study area; however, the overlying Rosebud seam thins and splits into several stringers westward toward NCRP 40A as the shaly to sandy parting between it and the McKay increases in thickness. Clinker formed by the burning of these two beds is spotty in occurrence; the coal is often either exposed at the surface or covered by a thin veneer of soil. The Rosebud-McKay was dry where it was encountered in Project wells.

Plate 5.4 View of Indian Coulee Priority Study Area. Rosebud Creek Valley in foreground, Indian Coulee in middle distance on right, Painted Hill in middle distance on left, Little Wolf Highland on horizon.

The underburden below the McKay is also coal-bearing. NCRP 35A encountered a 4.6 m (15 ft) section of the Robinson coal bed 82 m (270 ft) below the base of the McKay. As this seam lies too deep to be considered for surface mining, the hydrologic impact models will only concern the Rosebud and McKay seams. The interval between the Robinson and McKay also contains several thin seams of coal up to 1.5 m (5 ft) thick, separated by sandstone, shale, and in one well, a thin conglomerate (Figure 5.36).

Approximately 40 m (130 ft) above the Rosebud coal lies a sandstone unit up to 15 m (15 ft) thick, considered to be the westward extension of the Jimtown Sandstone; it forms light tan cliffs or pinnacles in numerous locations. The Sawyer coal lies within 10 m (33 ft) above this unit, and forms a significant clinker in the eastern part of the study area. The clinker becomes thin and spotty toward the west, as the seam thins and splits in that direction. The Sawyer is thought to merge with the Knobloch in the eastern part of the Reservation. A "striped zone" of alternating whitish and tan clays to silts can be found near the horizon of the Sawyer seam.

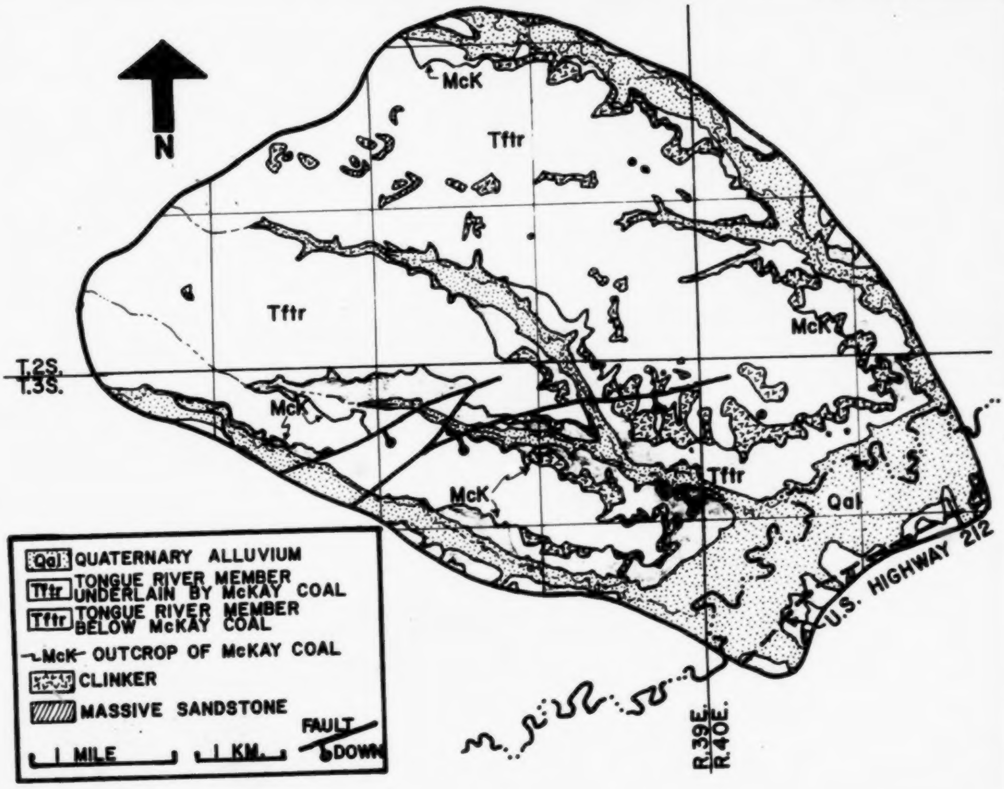

N
McK
Tftr
Tftr
McK
T.2S.
T.3S.
McK
McK
Tftr
Qal
U.S. HIGHWAY 212
R.39E.
R.40E.
Qal QUATERNARY ALLUVIUM
Tftr TONGUE RIVER MEMBER UNDERLAIN BY McKAY COAL
Tftr TONGUE RIVER MEMBER BELOW McKAY COAL
McK OUTCROP OF McKAY COAL
CLINKER
MASSIVE SANDSTONE
FAULT
DOWN
1 MILE
1 KM.

Figure 5.35. Geologic map of Indian Coulee Priority Study Area.

A few high buttes such as Painted Hill are capped by resistant clinkers which represent what is left of the Pawnee and possibly the Wall coal seams.

The floor of Rosebud Creek Valley and the lower reaches of the major tributary valleys are filled with alluvium. In places, Rosebud Creek contains at least 27 m (90 ft) of fill, and Butte Creek at NCRP 39A recorded 30 m (98 ft) of alluvium. Patchy gravel terraces representing old stream levels are found above the main alluvial valley.

Northeast- to east-trending faulting, possibly relating to the wrench system of the Lake Basin Fault Zone, occurs in the study area. Vertical displacement in places may possibly exceed 30 m (100 ft). The subsurface structure rises steadily toward the west where it is not broken by faulting.

Elevation at the base of the McKay increases from 1,020 m (3,350 ft) above MSL at NCRP 36A in Indian Coulee to 1,060 m (3,460 ft) at NCRP 40A in Butte Creek.

Although there is generally less overburden above the coal here than in the other two study areas, the Indian Coulee Priority Study Area may receive less pressure to be developed because the coal seams are the thinnest.

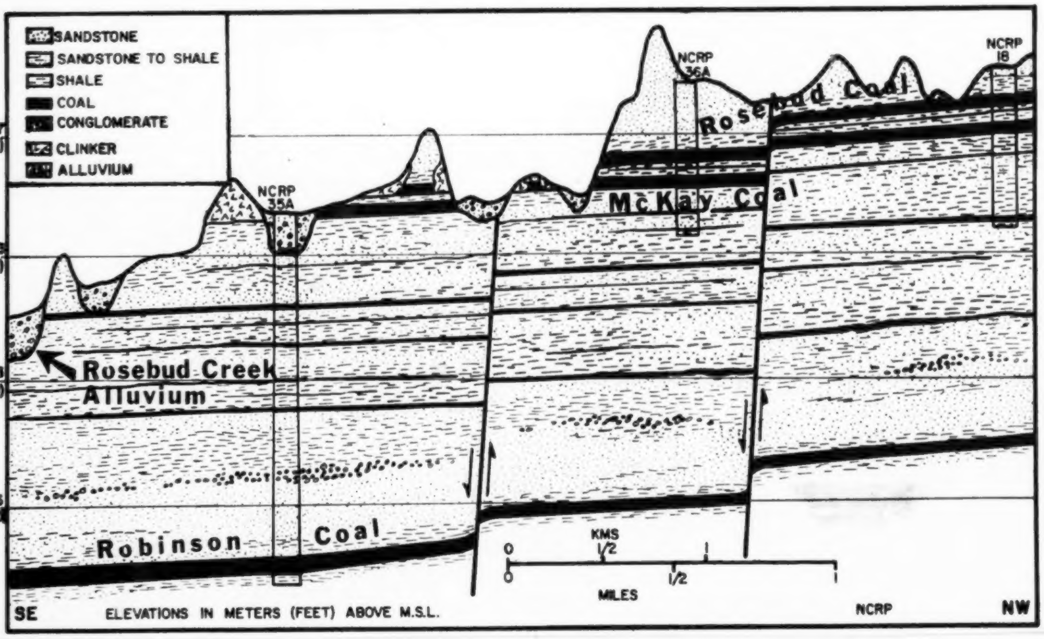

SANDSTONE
SANDSTONE TO SHALE
SHALE
COAL
CONGLOMERATE
CLINKER
ALLUVIUM
1037 (3400)
1006 (3300)
976 (3200)
946 (3100)
NCRP 35A
NCRP 36A
NCRP 18
Rosebud Coal
McKay Coal
Rosebud Creek Alluvium
Robinson Coal
KMS
0
1/2
1
MILES
0
1/2
1
SE
ELEVATIONS IN METERS (FEET) ABOVE M.S.L.
NCRP
NW

Figure 5.36. Geologic cross-section along Indian Coulee.

CHAPTER 6

GROUNDWATER

INTRODUCTION

The long terms effects of large scale energy development on local and regional groundwater systems of the west cannot be properly determined without careful identification of the pre-mining natural system. Definition of the hydrogeology of the area requires identification of the water bearing capacity of the subsurface materials; recharge and discharge rates; aquifer characteristics; flow systems; and groundwater quality.

Regional analysis of the hydrogeology identified six hydrostratigraphic units. Water availability information was developed for these units. The alluvium of the major stream valleys in the region and the sandstone, coal, and clinker of the Tongue River Member of the Fort Union Formation were found to form the principal near surface aquifers on the Reservation. The presence of measureable shale, silty shale, and thick continuous coal seams provide the framework for a number of stacked groundwater flow systems on the Reservation. These systems are influenced by the local and regional topography, as well as the hydrologic characteristics of the identified hydrogeologic units. The near surface groundwater moves from the higher central portion of the Reservation to the tributaries and main stem of Rosebud Creek and the Tongue River. Valley alluvium, clinker, and unconfined fine sandstones received the largest amounts of recharge. The hydraulic conductivities of the coal seams of the Tongue River Member ranged from 1.8 m/d (6 ft/d) to 0.07 m/d (0.23 ft/d). Extensive deposits of clinker were also found to be an intergral part of local and regional flow systems. Hydraulic conductivities were calculated to be 5.4 m/d (17.7 ft/d) and 11.1 m/d (64 ft/d) for the Anderson and Knobloch clinker, respectively. The wide variation in groundwater quality from well to well and area to area could be partially accounted for by bacterial sulfate reduction water quality models. Calcium magnesium sulfate water is dominate in confined flow systems not receiving direct recharge.

PREVIOUS REPORTS

All investigations examining the hydrogeology of the Northern Cheyenne Reservation have been reconnaissance reports. Renick (1929) was the first geologist to explore the region. Thom, et al. (1935) prepared a more detailed description of the geology of the Crow Reservation and western part of the Northern Cheyenne Reservation and Perry (1935) described the Tongue River Valley. Their discussions on water resources were based on field observation and were principally supply oriented. The United States Geological Survey completed a water supply atlas of southeastern Montana including the Northern Cheyenne Reservation in 1973 (Hopkins, 1973). A generalized potentiometric surface representing the probable altitude of the first available water plus limited groundwater quality data were presented. The BIA contracted with Hurlbut, Kersich, and McCullough and Associates of Billings, Montana (1972,1973,1975) to prepare a three phase water resource report which summarized the existing water resource data for the Northern Cheyenne Reservation. The hydrogeologic sections included Hopkin's (1973) data and summarized limited water quality data collected by the U.S. Indian Health Service. They concluded that there was not sufficient information available to estimate groundwater recharge, discharge and storage for the Reservation. No attempt was made at flow system or hydrostratigraphic definition. The U.S. Bureau of Mines (BM) began a study to model the near surface groundwater systems in the Powder River Basin in 1976. However, work is still in the preliminary stage and results of the project were not availbale at the preparation of this report. Initial analyses of project generated hydrogeologic data were prepared by Woessner (1978) as a Ph.D disertation.

METHODS

Well driller logs and water quality reports available in 1975 from the Northern Cheyenne Housing Authority and Indian Health Service were evaluated and a 57-well monitoring network was designed, constructed, and operated. The monitoring program was extended to 81 wells by the fall of 1976 (Figure 6.1). Thirty of the network wells were existing wells and 51 were constructed by the NCRP to provide data in areas without available monitoring points. Wells were selected and designed to provide accurate data on the hydrostatic head, degree of confinement, annual changes in storage, horizontal and vertical gradients, and hydrogeologic parameters of aquifers. The wells were also used to obtain water samples for quality analyses from various water bearing strata. In addition to the 81 well monitoring network, an extensive hydrogeologic inventory catalogued 208 domestic wells and springs.

Wells were constructed at 45 sites using 10.2 cm (4 in) inner diameter PVC casing and at six sites using 0.38 cm (1.5 in) inner diameter PVC casing. Originally, well design included the placement of cement in the bottom of the hole to seal off the underlying strata. However, this practice was abandoned when cement contamination was noticed in water samples from those wells. All later wells were gravel packed from the bottom to about 1.8 m (6 ft) above the perforations (Figure 6.2).

The location, owner and well-completion information for each well is presented in Appendix B. At sixteen monitoring sites, two wells were nested using individual holes to provide data on hydrologic units at different depths. Well elevations were interpreted from USGS topographic maps.

Water levels in the network wells were monitored monthly with a steel tape or an electric water level probe. Four continuous recorders monitored water level changes in selected wells on an intermittent basis. Water quality samples were pumped or bailed quarterly from 61 of the 81 wells. Temperature, specific conductance, and pH were determined in the field for each sample.

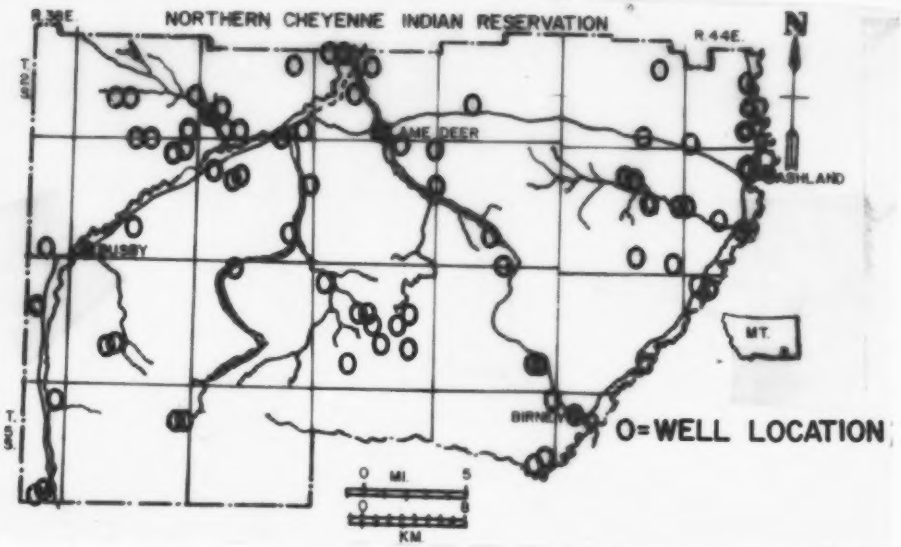


Figure 6.1. The locations of the monitoring wells installed by NCRP on the Northern Cheyenne Reservation.

Samples were filtered in the field through a 0.45 micron filter and a portion of each sample was preserved for metals analyses by acidifying it with nitric acid. Analyses for 20 standard constituents and 16 trace metals were performed by Energy and Environmental Resource Consultants, Inc., Billings, Montana. The list of constituents analyzed and methods of analyses are presented in Appendix B.

Preliminary short term aquifer tests conducted on NCRP completed wells, 163 specific capacity tests from driller logs and 29 plug tests on NCRP cores were utilized to define hydrogeologic parameters of Reservation aquifer systems.

Because of the size of the Reservation and the inherent limitations of time and expense, three Priority Study Areas were selected for detailed study as described in CHAPTER 5 - GEOLOGY (Figure 5.3). Thirty eight wells were constructed in the Priority Study Areas. Detailed flow system and aquifer parameter analyses were conducted for each site. Two continuous cores, penetrating the principal coal aquifer, were taken within each area. Intervals from each of the cores were selected for permeability testing. Composite samples of drill cuttings from well drilling in and surrounding the Priority Study Areas were utilized for overburden and leachate testing.

The regional hydrogeology was described in addition to the specific hydrogeology of the Reservation. Six hydrostratigraphic units as well as groundwater movement in the region were determined from the available literature and data developed during this project.

domestic, stock, and irrigation water supplies.

Tongue River Member Unit

The Tongue River Member Unit is Tertiary in age and crops out at the surface over much of the area. This unit is composed of numerous seams, sandstones, siltsone, clinker, and interbedded sandstone, siltstone and shale. The coal, sandstone, and clinker are the principal water bearing rocks of this unit. Well yields generally range from less than 3.2 lpm (2 gpm) in coal seams, to greater than 80 lpm (50 gpm) in sandstone and clinker deposits. Total dissolved solids range from less than 500 mg/l to more than 3,000 mg/l. The principal ions are similar to those found in the Unconsolidated Unit. The Tongue River Member Unit has been further separated into three hydrogeologic units for the Reservation area where more detailed data were available.

Tullock-Hell Creek Unit

The Tullock-Hell Creek Unit is Tertiary and Upper Cretaceous in age and consists of the lower Tullock Member of the Fort Union Formation and the Hell Creek Formation. The Tullock-Hell Creek Unit underlies the region cropping out near the Yellowstone River. The unit materials are sandstones and interbedded shales with thin coal beds in the upper portion of the Tullock Member (USGS, 1974). The Tullock-Hell Creek Unit is 213 to 274 m (700 to 900 ft) in thickness (Hopkins, 1973). Thirty to one hundred meters (100 to 350 ft) of Lebo shale separates the Tullock-Hell Creek Unit from the Lower Tongue River Member Unit. This dark shale with lignite is reported to yield water locally from sandstone lenses, however, water is usually highly mineralized (USGS, 1975).

Five wells in the Ashland area just east of the Reservation are finished in this aquifer. Two municipal wells, one for the town of Ashland and one for the Labre School, yield 303 lpm (80 gpm) and 227 lpm (60 gpm), respectively, from this aquifer. A stock well in the Otter Creek area yields about 3.9 lpm (1 gpm) (Hopkins, 1973). Westmoreland EIS (BIA, 1976) reports stock and domestic wells to the northwest of the Reservation finished in a "Lebo Shale-Tullock Aquifer" yield less than 38 lpm (10 gpm) of sodium sulfate, sodium-bicarbonate water to wells. Analyses of water quality data from wells finished in the Tullock-Hell Creek Unit showed the water is sodium-bicarbonate type with TDS levels of about 1,000 mg/l (Hopkins, 1973).

Lakota Sandstone Unit

The Lakota Sandstone Unit is Lower Cretaceous in age and consists of the Lakota Sandstone Member of the Cloverly Formation (BIA, 1976). The unit underlies southeastern Montana. It is separated from the Tullock-Hell Creek Unit by approximately 1340 m (4,400 ft) of material of low permeability and is up to 61 m (200 ft) in thickness. It consists of a claystone with beds of medium to coarse sandstone in the basal portions (USGS and BM, 1975). No data are available on yields obtained from this unit. Thom, et al. (1935) noted artesian flows were encountered in many wells drilled for oil in the Cloverly Formation, and water may contain natural gas and traces of petroleum.

Madison Unit

The Madison Unit is Mississippian in age and consists of the Lodgepole Limestone, the Mission Canyon Limestone, and the Charles Formation, or the Madison Group (Konikow, 1976). The aquifer is reported to be up to 450 m (1,500 ft) thick and consists of extensive limestone and dolomite with shale, evaporate, and cherty zones (Konikow, 1976).

Estimated yield data calculated for proposed industrial use indicates that these wells could yield as much as 7,580 lpm (2,000 gpm) from portions for the aquifer. Wells completed in the Madison Unit are located at Colstrip north of the Reservation and at the Westmoreland mine to the northwest of the Reservation. It is estimated from figures on dust control and in-house needs that the Westmoreland well probably yields 265 to 682 lpm (70 to 180 gpm).

Water quality data indicate water is generally a calcium sulfate type which is high in salinity (BIA, 1976). Water temperatures average about 83°C or 180°F (Konikow, 1976).

Red River Unit

The Red River Unit is Ordovician in age and consists of the Red River Formation. It underlies the entire Reservation. The aquifer is separated from the Madison Unit by 73 m (240 ft) of low permeability material and is approximately 95 m (310 ft) thick. The Red River Unit is composed of a granular dolomite (USGS, 1975). This source of water is mentioned in the BIA and Westmoreland reports. However, no information is available about the yield and water quality of this unit.

MOVEMENT OF GROUNDWATER

A regional description of groundwater movement is difficult because of the limited data base. Data developed by the USGS to describe the near surface (less than 150 m [500 ft] deep) groundwater movement are the only information available which describe the regional groundwater movement.

Near Surface Groundwater Movement

In an attempt to delineate the pattern of near surface groundwater movement, Hopkins (1973) conducted a reconnaissance hydrologic survey of the southern part of Rosebud County, the eastern portion of Big Horn County, and the western portion of Powder River County. Data were collected for the Unconsolidated Unit and Tongue River Member Unit. The results of this study are shown in Figure 6.3. It can be concluded from this work that the generally horizontal beds, topography, and major surface water drainages control groundwater

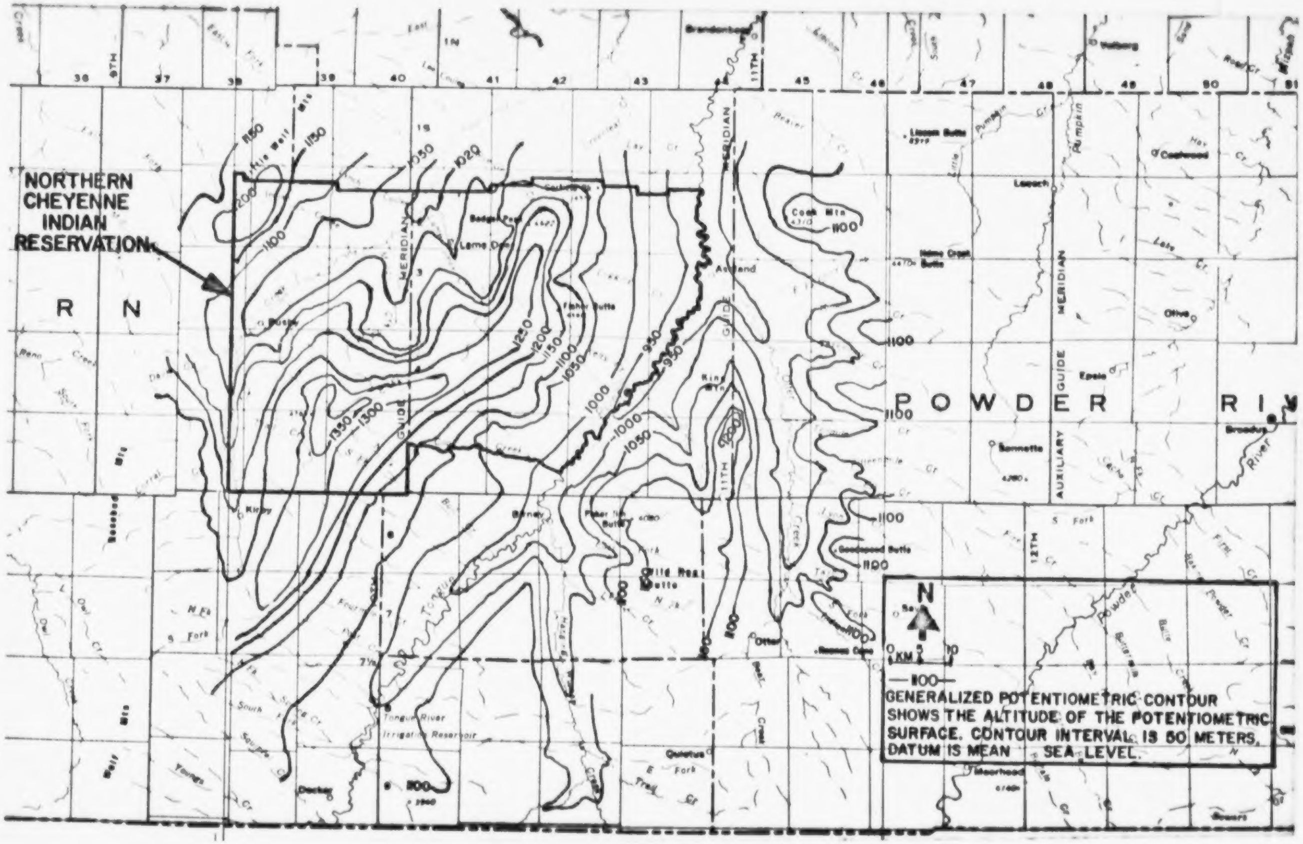

NORTHERN CHEYENNE INDIAN RESERVATION
POWDER RIV
R N
MERIDIAN
GUIDE MERIDIAN
AUXILIARY GUIDE MERIDIAN
11TH
12TH
9TH
1350
1300
1250
1200
1150
1100
1050
1020
1000
950
N
0 5 10 KM
—1100—
GENERALIZED POTENTIOMETRIC CONTOUR SHOWS THE ALTITUDE OF THE POTENTIOMETRIC SURFACE. CONTOUR INTERVAL IS 50 METERS, DATUM IS MEAN SEA LEVEL.

Figure 6.3. Generalized potentiometric surface in southeastern Montana (after Hopkins, 1973).

movement in the region. Water is recharged to the system in high plateau areas and to outcrops of clinker, sandstone, and alluvium by direct precipitation and water discharges to the major streams in the region.

Deeper Groundwater Movement

Information available on the occurrence and movement of groundwater beneath the Tongue River Member Unit comes from limited well data and the literature. In both the Rosebud Creek Valley and Tongue River Valley there are wells which are believed to penetrate the Tongue River Member Unit. In all cases these wells indicate that what is possibly the Tullock-Hell Creek Unit is a confined system. Unfortunately, sufficient data are not available at this time to determine the direction of groundwater movement or recharge- discharge areas. It is believed that the Lakota Sandstone Unit is also a confined system in the region. No wells in this area penetrate the Lakota Sandstone. The confined Madison Unit is present beneath the region and is utilized as a source of water by the Westmoreland Mine and by the town of Colstrip. From data prepared by the USGS in Water Resource Investigation 63-75 Plate 1, it is apparent that groundwater is recharged to the Madison Unit system along the northeastern slope of the Bighorn Mountains and the western slope of the Black Hills, and moves from the southwest to the northeast and north passing beneath the Reservation (Figure 6.4).

QUANTITY OF GROUNDWATER

It is difficult to quantify the groundwater resources on a regional basis with the limited available data base. Groundwater is the principle source of domestic, stock, and municipal water in the region. However, a general discussion of the quantity of groundwater in storage and hydrologic properties of units cannot be assessed.

RESERVATION HYDROGEOLOGY

OCCURRENCE OF GROUNDWATER

The geologic framework within which the groundwater of the Reservation occurs is complex. Sandstone, siltstone, and shale interfinger at random between coal beds which split, merge, and pinch out. Linear belts of clinker border the highlands, forming ridges and plateaus which parallel stream valleys. Where permeable rock units are uniform and continuous below the water table, they are saturated and yield water to wells and springs. However, it is more often the case that units grade into each other. Therefore, differentiation of singular hydrologic units is difficult. The largest amount of data on the occurrence of groundwater on the Reservation is information from domestic wells. Almost all of the dwellings in the area have individual wells. However, most are located along the major streams of the Reservation and a large percentage of these wells are completed in alluvial material. Vast areas of the Reservation are without well data. Thus, aquifers are not easily traceable.

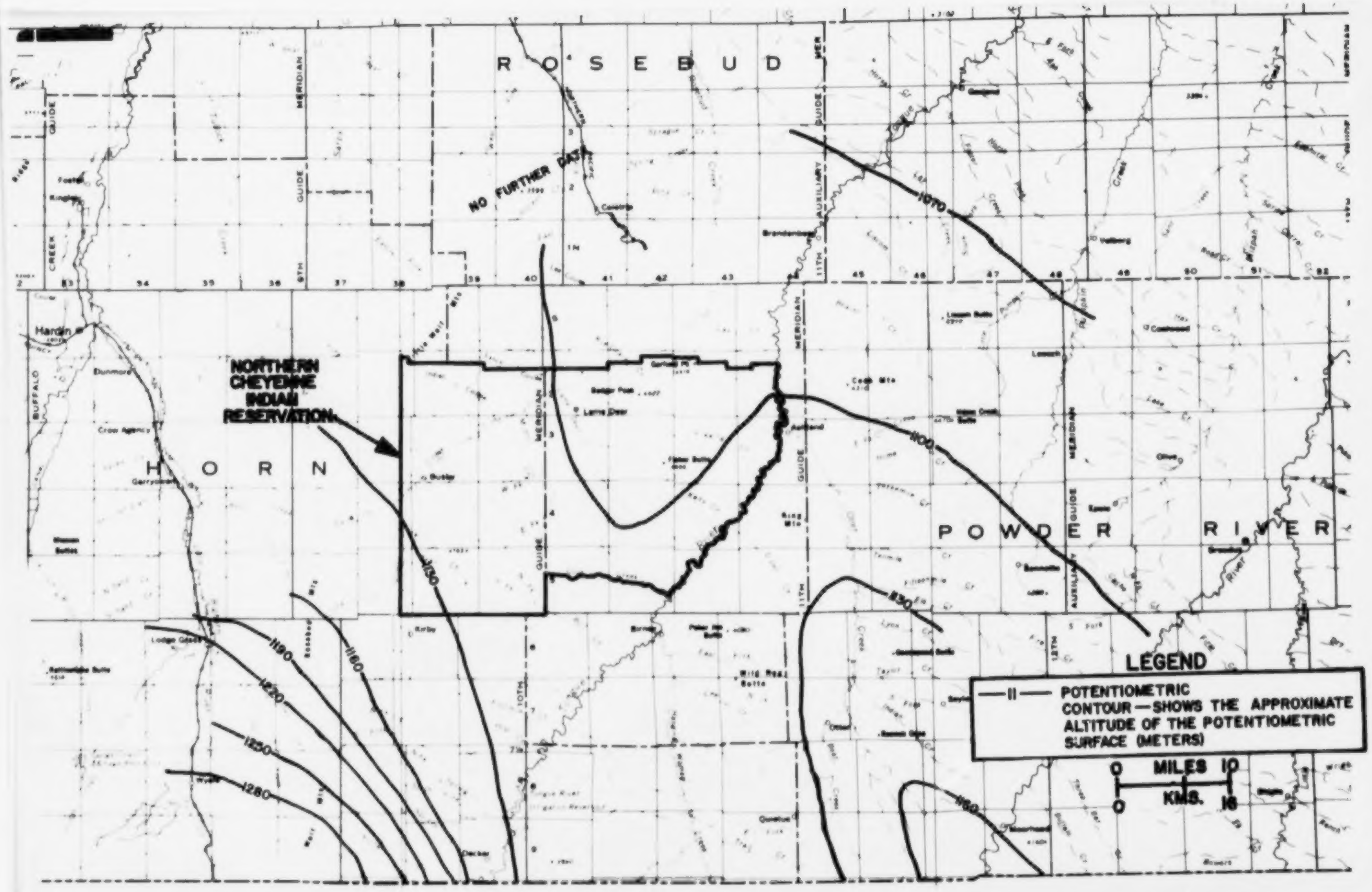

R O S E B U D
NO FURTHER DATA
NORTHERN CHEYENNE INDIAN RESERVATION
H O R N
P O W D E R
R I V E R
Hardin
Dunmore
Crow Agency
Garryowen
Lodge Grass
Busby
Lame Deer
Ashland
Birney
Decker
Quietus
Moorhead
Broadus
Powderville
Volborg
Brandenberg
Colstrip
Forsyth
Kingsbury
1070
1100
1130
1160
1190
1220
1250
1280
830
1160
MERIDIAN
GUIDE
AUXILIARY
LEGEND
—II— POTENTIOMETRIC CONTOUR — SHOWS THE APPROXIMATE ALTITUDE OF THE POTENTIOMETRIC SURFACE (METERS)
0 MILES 10
0 KMS. 16

Figure 6.4. Generalized potentiometric surface of the Madison Aquifer (after Konikow, 1976).

Regionally six hydrostratigraphic units were identified (Table 6.1). The main focus of this study was the Unconsolidated Unit and Tongue River Member Unit which contain the near surface (less than 160 m (500 ft) below land surface) aquifer systems of the Reservation. Thick coal seams, extensive clinker deposits, channel sandstone, valley fill and alluvium were identified as the major water bearing materials in the area. Description of the Reservation hydrogeology includes the Unconsolidated Unit and three recognized subdivisions of the Tongue River Member Unit. Discussion of the Unconsolidated Hydrostratigraphic unit as it specifically relates to the Reservation does not include any subdivisions on the Reservation because subunits were not definable. The Tongue River Member Hydrostratigraphic Unit was subdivided into three subunits on the basis of identifiable hydrogeologic similarity, hereafter referred to as hydrogeologic units.

Criteria for defining a hydrogeologic unit included:

1. Earth materials having similar hydrogeologic properties;
2. Groundwater movement within each unit being distinguishable from movement in other associated units;
3. The unit's mappability.

The Tongue River Member Hydrostratigraphic Unit was subdivided into three hydrogeologic units: the Anderson Unit, the Knobloch Unit, and the Lower Tongue River Member Unit (Table 6.2). Figure 6.5 is a schematic of these units depicting their relative position and location.

The Anderson Unit is composed of massive clinker deposits that form an extensive plateau in the central portion of the Reservation, and of the thick Anderson coal seam which is in direct contact with the clinker. Water enters the coal and clinker by direct recharge. Much of the water discharges as spring flow at the shale coal-clinker interface. The coal and clinker are underlain by a relatively extensive shale which separates this unit from the underlying Knobloch Unit.

The Knobloch Unit is composed of a sequence of permeable thick coal seams, lenticular sandstone,and clinker zones which occur in coal outcrop areas. These materials are separated by less permeable shale and siltstone. Major zones of coal seams, sandstones and clinker direct groundwater movement, a large portion of which moves laterally to discharge as springs and to major surface water drainages. A relatively extensive shale layer underlies the massive Knobloch coal sequence.

The Lower Tongue River Member Unit, is composed of permeable lenticular channel sandstones and minor coal beds, which are contained in a thick shale-siltstones sequence. Groundwater flows in the coals and sandstones. The unit is underlain by the thick Lebo Shale Member of the Tongue River Member.

It is believed that a complex stacked groundwater system is operating within the reservation. A description of the Unconsolidated Hydrostratigraphic Unit and the Tongue River Member Hydrostratigraphic Unit follows.

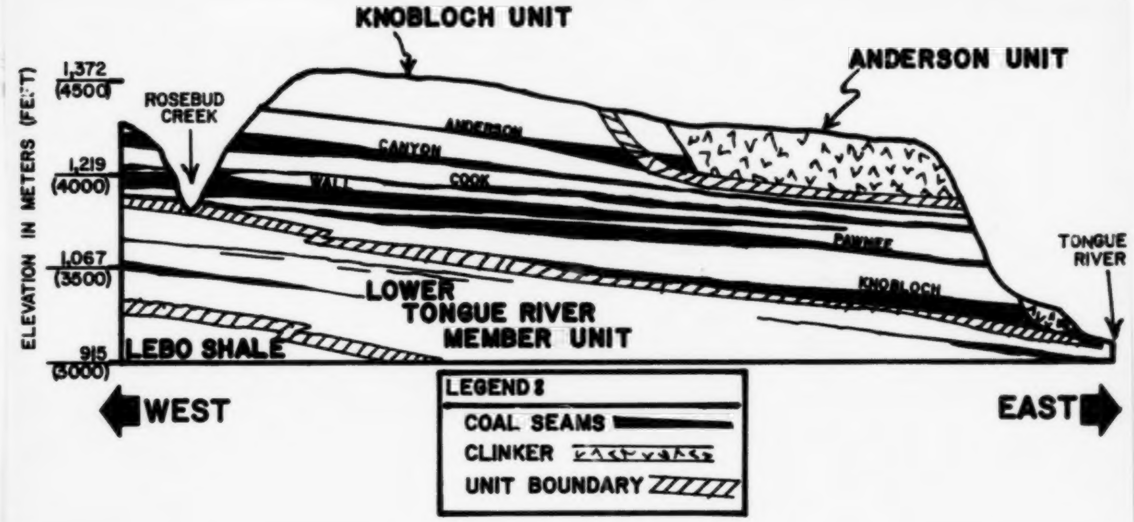

KNOBLOCH UNIT
ANDERSON UNIT
1,372 (4500)
1,219 (4000)
1,067 (3500)
915 (3000)
ELEVATION IN METERS (FEET)
ROSEBUD CREEK
ANDERSON
CANYON
WALL
COOK
PAWNEE
KNOBLOCH
TONGUE RIVER
LOWER TONGUE RIVER MEMBER UNIT
LEBO SHALE
WEST
EAST
LEGEND:
COAL SEAMS
CLINKER
UNIT BOUNDARY

Figure 6.5. Hydrogeologic Units in the Tongue River Member on the Northern Cheyenne Reservation.

Unconsolidated Hydrostratigraphic Unit

The Unconsolidated Unit is Quaternary in age (less than two million years old). It underlies and borders the principal tributaries of the Reservation with major deposits in the valleys of Rosebud Creek (0 to at least 29 m [0 to 90 ft] thick), Lame Deer Creek, (0 to 18m [0 to 60 ft] thick), Cook Creek (0 to 15 m [0 to 50 ft] thick), Muddy Creek (0 to 37 m [0 to 120 ft] thick), and the Tongue River (0 to 33 m [0 to 110 ft] thick), see Figure 6.6. The Unconsolidated material is alluvium composed of clay, silt, sand, and gravel including numerous fragments of clinker. The Unconsolidated material is described on driller's logs as a mixture of sand, gravel, and clinker fragments or, locally, as scoria wash. No continuous beds of sand and gravel were recognizable. Silt and clay occur as thin lenses separating sand, plus sand and gravel deposits.

The Unconsolidated Unit is the source of water supply for 80 for the 208 domestic wells inventoried. The domestic wells yield 37.9 to 78.8 lpm (10 to 20 gpm). Larger diameter wells at Ashland Cluster, Birney Village and the town of Ashland in the Tongue River Valley alluvium yield 68.2 lpm (18 gpm), 189.5 lpm (50 gpm), and 947.1 lpm (250 gpm), respectively. No irrigation wells utilizing the Unconsolidated Unit are present on the Reservation.

TABLE 6.1. HYDROSTRATIGRPHIC UNITS OF THE FORT UNION COAL REGION, SOUTHEASTERN, MT.

					WATER SUPPLY			
					YIELD*		QUALITY**	
					WELLS AND SPRINGS			
		THICKNESS						
UNIT	AGE	M.	FT.	DESCRIPTION	lpm	gpm	MAIN IONS	TDS-(mg/l)
Unconcolidated Unit	Quaternary	0-45	0-150	Clay, silt, sand, gravel	37.9-2653	10-700	Na, Ca, Mg HCO_3, SO_4	612-3500
Tongue River Member	Tertiary	0-340	0-1100	Sandstone, clinker, coal interbedded shale and silt.	3.2-80	2-50	Na, Ca, Mg HCO_3, SO_4	500-4000
Tullock-Hell Creek	Tertiary Cretaceous	213-274	700-900	Shale, Siltstone, sandstone, coal. Sandstone is the principal unit.	3.8-303	1-80	Na, HCO_3	1000
Lakota Sandstone	Cretaceous	61	200	Claystone with a basal medium to coarse sandstone. Sandstone is the principal unit.	--	--	--	--
Madison	Mississi-pian	341	1120	Limestone, dolomite, shale, evaprites and cherty zones. Limestone and dolomite are principal units.	265-7580	70-2000	Ca, So_4	--
Red River	Ordovician	73	240	Granular dolomite	--	--	--	--

* lpm - liters per minute
gpm - gallons per minute

** TDS-mg/l total dissolved solids - milligrams per liter

TABLE 6.2. HYDROGEOLOGIC UNITS OF THE TONGUE RIVER MEMBER HYDROSTRATIGRAPHIC UNIT

					WATER SUPPLY			
					YIELD*		QUALITY**	
		THICKNESS			WELLS AND SPRINGS			
UNIT	AGE	M	FT	DESCRIPTION	lpm	gpm	MAIN IONS	TDS-(mg/l)
Anderson Unit	Tertiary	0-91	0-300	Shale, siltstone, sandstone, coal, clinker. The Anderson coal seam and clinker are the principal units.	3.8-349	1-92	Na, HCO_3, Ca, Mg, HCO_3	280-3000
Knobloch Unit	Tertiary	0-111	0-366	The Knoblock, Wall, Canyon coal seams, their associated clinker and sandstones are the principal units.	0.7-94.8	0.2-27	Na, HCO_3, Ca, Mg, SO_4	200-3000
Lower Tongue River Member Unit	Tertiary	96-151	315-495	Shale, siltstone, sandstone, coal, clinker. The Rosebud McKay-Flowers Goodale and the Robinson coal seams are the principal units.	3.8-75	1-20	Ca, Mg, HCO_3, SO_4, Na	295-3300

* lpm - liters per minute
gpm - gallons per minute
**TDS-mg/l - total dissolved solids-milligrams per liter

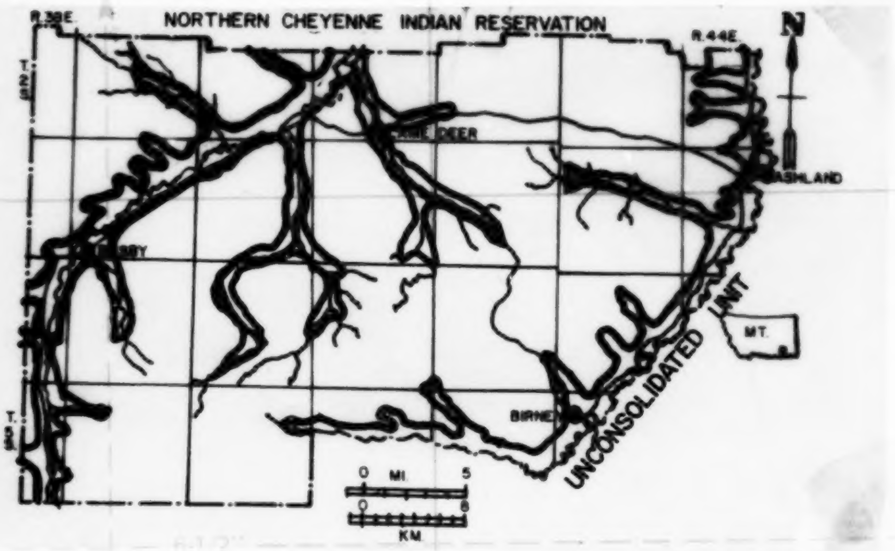


Figure 6.6 Location of the Unconsolidated Hydrogeologic Unit.

However, a well located in the Cook Creek unconsolidated material on the Moreland Ranch just south of the Reservation boundary is reported to yield between 1516 and 2653 lpm (400 to 700 gpm).

Tongue River Member Hydrostratigraphic Unit

Anderson Hydrogeologic Unit

The Anderson Unit is Paleocene in age (apporximately 60 million years old) and consists of the upper portion of the Paleocene Tongue River Member of the Fort Union Formation. Isolated deposits of the younger Wasatch Formation may occur as part of this hydrologic unit. The Anderson Unit occurs in the Divide Highland and Divide Clinker Plateau region (Figure 6.7).

The regional dip is to the southeast. Aquifer materials consist of fine sandstone, siltstone, shale, coal, and clinker from the base of the Anderson coal seam to the surface. The Anderson Hydrogeologic Unit ranges in thickness from zero at its boundaries to 124 m (400 ft) beneath Cook Creek Butte in the southwestern portion of the area. Analyses of drill log data indicate that beds of permeable sandstone and siltstone occur principally as discontinuous lenses which grade from shale to siltstone to sandstone and back into shale. The Anderson coal seam and its related clinker deposits form the thickest single unit within this aquifer. Water-bearing Anderson coal varies from 1.5 to 19.8 m (5 to 65 ft) thick in the southern portion of the area, thinning out to the west. Massive clinker related to the burning of the Anderson varies from 30 to 60 m (100 to 200 ft) thick in the central and northern portions of the region. Both the clinker and coal are fractured and permeable.

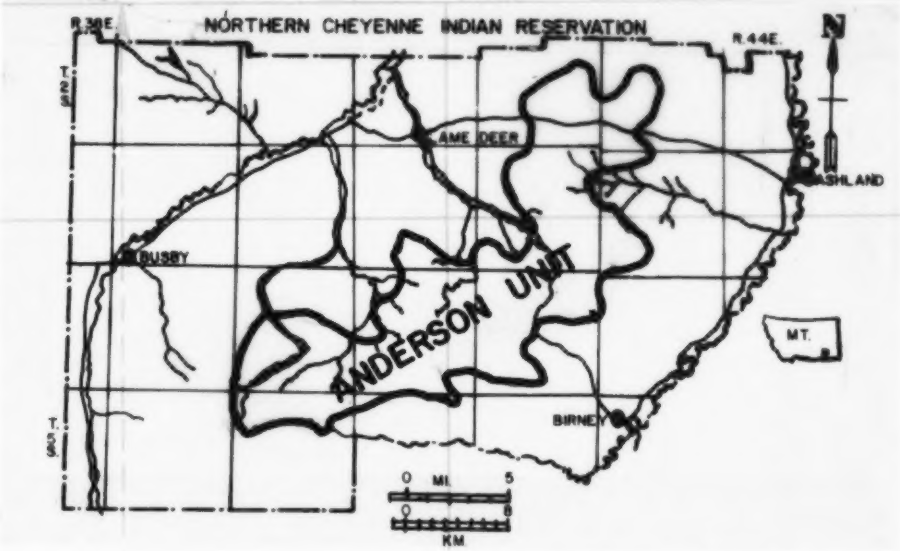


Figure 6.7. Location of the Anderson Hydrogeologic Unit.

Two windmills, nine NCRP monitoring wells, and over 35 mapped springs derive water from the Anderson Unit. Preliminary development pumping of monitoring wells finished in the Anderson coal seam yielded from 3.8 to 11.4 lpm (1 to 3 gpm). Springs associated with sandstone and siltstone above the Anderson Unit yield up to 3.8 lpm (1 gpm) of water. Springs emanating from the base of the unit, usually at clinker-shale contacts, flow at rates of 3.8 to 349 lpm (1 to 92 gpm).

Knobloch Hydrogeologic Unit

The Knobloch Unit is Paleocene in age and consists of a portion of the Tongue River Member of the Fort Union Formation. The unit is located beneath the Anderson Unit in the central and eastern portions of the Reservation, south and east of Rosebud Creek (Figure 6.8). An isolated portion of the unit may be present in the Sarpy Mountains to the northwest of Rosebud Creek. The regional dip of the unit is to the southeast.

The Knobloch Unit is similar to the overlying sandstone, siltstone, shale, coal and clinker. The Unit extends from the base of the Knobloch coal seam to a thin shale layer at the base of the Anderson coal seam. The Knobloch Unit ranges in thickness from zero to 350 m (1150 ft) in the central portion of the Reservation. The Wall, Canyon, Pawnee and Knobloch-Sawyer-Nance coal beds, their associated clinker, and associated thick interburden sandstones form the principal water bearing units.

The Wall coal seam, 1.5 to 18.3 m (5 to 60 ft) thick, and its related clinker form a continuous unit. Both the Wall and its clinker are fractured and permeable. The Canyon coal seam lies between the Anderson and the Wall

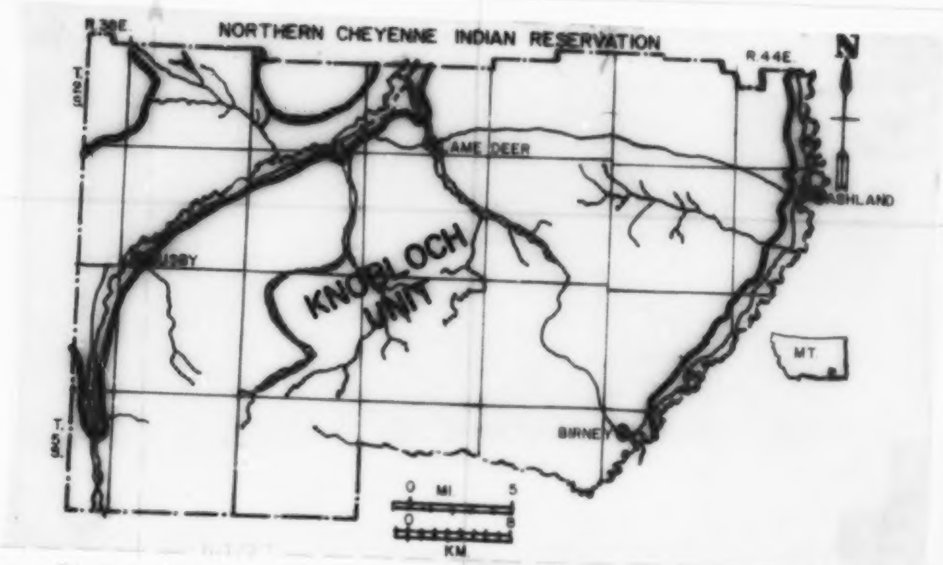


Figure 6.8. Location of the Knobloch Hydrogeologic Unit.

coal seams, and forms a continuous water bearing unit 6 to 9 m (20 to 30 ft) thick in the Bull Creek Tower area.

The Knobloch coal seam, 6 to 21 m (20 to 70 ft) thick, occurs over most of the Reservation. The Sawyer coal seam, 1 to 9 m (5 to 30 ft) thick, occurs over much of the area west of the Tongue River Valley. The related clinkers of the Knobloch and Sawyer seams are fractured and permeable.

Fourteen windmills, 28 springs, 37 domestic wells, one municipal well and ten monitoring wells are finished in this unit. The domestic wells, most of which are located in Lame Deer Valley, are finished in sandstone. The wells yield from 30 to 60 lpm (7 to 14 gpm). Monitoring wells finished in the Knobloch coal seam yielded 4 to 15 lpm (1 to 4 gpm). The Lame Deer Village well is finished in the Sawyer clinker. It yields 190 lpm (50 gpm). Spring flow associated with sandstone clinker and coal outcrops is generally less than 95 lpm (25 gpm).

Lower Tongue River Member Hydrogeologic Unit

The Lower Tongue River Member Unit is Paleocene in age and consists of the lower portion of the Tongue River Member of the Fort Union Formation. The Lower Tongue River Member Unit underlies the entire Reservation area. The regional dip of the unit is to the southeast.

The unit consists of sandstone, silstone, shale, coal, and clinker and extends from the Lebo Shale Member of the Fort Union Formation to the shale beneath the Knobloch coal seam. It is generally 160 m (500 ft) thick, except in the valleys of Rosebud Creek and the Tongue River where erosion has reduced the total thickness by 31 to 46 m (100 to 150 ft). Beds of permeable sandstone and shale are discontinuous and occur primarily as lenses, which grade from shale to siltstone to sandstone and back into shale. However, the mapped Jimtown sandstone in the Rosebud Creek area is at maximum 30.5 (100 ft) thick at the outcrop. Analyses of well logs in the Rosebud Creek Valley indicated the presence of saturated sandstone. The most continuous coal seams in this unit are the Rosebud coal (1.5 to 3.1 m [5 to 10 ft] thick), the McKay coal (1.5 to 3.1 m [5 to 10 ft] thick) and the Robinson coal (3.1 to 6.1 m [10 to 20 ft] thick). Both coal and related clinker provide avenues for water flow via fracture permeability.

Water supply data for this unit are limited to 5 springs, 55 domestic wells, 2 municipal wells, and 12 monitoring wells. Springs generally yield 3.8 lpm (1 gpm). Domestic wells are usually finished in sandstone and yield from 30.3 to 75.8 lpm (8 to 20 gpm). The central supply wells at Muddy Cluster, south of Rosebud Creek and the town well at Busby are finished in sandstone and yield 68.2 lpm (18 gpm) and 189.5 lpm (50 gpm), respectively. Preliminary tests of monitoring wells completed in the Rosebud, McKay and Robinson coal seams indicate wells will probably yield less than 18.9 lpm (5 gpm).

There is approximately 61 to 213 m (200 to 700 ft) of the Lebo Shale Member of the Fort Union Formation beneath the Tongue River Member. It should be noted that the hydrostratigraphic units discussed in the Regional Hydrogeology subsection underlie the Tongue River Member Unit. These units are separated by varying thicknesses of materials with low permeabilities.

QUANTITY OF GROUNDWATER

Storage

The quantity of water in storage in the hydrogeologic units of the Reservation is determined by the saturated thickness, porosity, and areal extent of the units. Only a portion of the water filling the voids of an aquifer is free to drain by gravity; the remainder is held to the surfaces of the pores by surface tension. However, not all of this available water can be practically removed by wells. Pump test methods of calculating aquifer storage were not utilized because sufficient test data were not available.

The specific yields of the unconsolidated clay, sand, and gravel of the principal stream valleys were determined by reviewing well logs to determine saturated thickness and by utilizing specific yield values for each lithology within the saturated thickness (Johnson, 1967). These values were multiplied by the thickness of the respective units, totaled, and averaged to obtain total storage per unit surface area. This information was then combined with the area of the mapped unit to yield storage information.

The average saturated aquifer thicknesses of unconsolidated material were calculated from existing well logs for Rosebud Creek Valley, including Rosebud Creek (11 m, [35 ft]), Muddy Creek (9 m, [30 ft]), Lame Deer Creek (11 m, [35 ft]), and the Tongue River alluvium (11 m, [36 ft]). A saturated thickness of 3 m (10 ft) was assumed for the Cook Creek Valley, and a saturated thickness of 1.5 m (5 ft) was assumed for all other major drainages. Data for wells fully penetrating the unconsolidated material were limited. It is believed that calculated average values are conservative and that the main valleys of Rosebud Creek and the Tongue River may contain from 12 m (40 ft) to 24 m (80 ft) of saturated unconsolidated material.

The weighted specific yield of the unconsolidated material in Rosebud Creek Valley and in Tongue River Valley is 0.15. The storage calculations, including the planimetering of the mapped area, were done in cooperation with Mr. James McGill of HKM Associates of Billings, Montana. Estimates of the quantity of groundwater stored in the unconsolidated material are given in Table 6.3. The total quantity of groundwater stored in the unconsolidated material of the Reservation is estimated to be 19,400 hectare meters (156,800 acre ft) or $1.9 \times 10^8 m^3$ ($6.9 \times 10^9 ft^3$).

TABLE 6.3. ESTIMATED VOLUMES OF GROUNDWATER STORAGE

Hydrogeologic Unit	Average Estimated Thickness m	ft	Specific Yield	Area Hectares	Acres	Volume of Storage Hectare Meters	Acre feet	Cubic Meters	Cubic feet
UNCONSOLIDATED									
Rosebud Creek	10.7	35	0.12	8,971	22,168	11,500	93,100	1.15×10^8	4.1×10^9
Tongue River	11	36	0.15	4,777	11,804	7,900	63,700	0.79×10^8	2.8×10^9

Calculation of water stored in consolidated unconfined aquifers was not attempted because these units were not easy to map and data on saturated thickness were lacking. However, specific yields for the unconfined consolidated material were assigned based on the general literature and professional judgement (Table 6.4). These specific yields were utilized in flow systems and impact analyses.

Storage coefficients for individual confined units were estimated using the methods described by Lohman (1972). Values were obtained by multiplying the aquifer thickness by 10^{-6}.

Hydraulic Conductivities

Hydraulic conductivity and transmissivity were determined from analyses of field pump tests, analyses of drillers' development tests, laboratory permeability tests, and literature values.

TABLE 6.4. SPECIFIC YIELD OF UNCONFINED UNITS ON THE NORTHERN CHEYENNE RESERVATION

UNIT	SPECIFIC YIELD
Unconsolidated Material	
Tongue River Valley	0.15
Rosebud Creek Valley	0.12
Clinker	0.10
Sandstone	0.01
Coal	0.01

Drillers' development tests, which are conducted on newly constructed domestic wells, were recorded in 168 well logs on the Reservation. Wells were pumped at a constant rate from one to four hours and total drawdown was recorded before pumping stopped. Thirty-one NCRP monitoring wells were pump-tested for time intervals of less than one hour. Thirteen tests yielded sufficient data to estimate hydraulic conductivities for various coal seams and one clinker unit. Pump-test data were analyzed using the modified non-equilibrium Theis equation as developed by Jacob (1973) for non-equilibrium conditions and the Thiem (1906) equation for equilibrium conditions.

Laboratory permeability testing of 29 selected intervals of NCRP cores were conducted using air permeability plug tests. Porosity, and horizontal and vertical air hydraulic conductivities were measured on each sample by Energy and Environmental Consultants Inc., of Billings, Montana. A detailed description of the techniques used in analyzing pump test data from drillers' logs, NCRP pump test data and laboratory plug test data is presented in Appendix B.

More than 40 pump test results are reported in the literature in geologic formations near the Reservation. These were used to evaluate the range of aquifer parameters and the reasonableness of techniques utilized to estimate parameters. Pump test data from drillers' logs, NCRP tests, and slug tests yielded a large volume of highly variable information. Results of analyses and a literature search are given in four tables in Appendix B.

Unconsolidated Hydrostratigraphic Unit

Pump test data from drillers' logs were utilized to determine hydraulic conductivities for the Unconsolidated Unit. Sixty-three tests were reported for wells finished in unconsolidated material of the major stream valleys in the area. Analyses of data yielded average hydraulic conductivity values of

6.4 m/d (21 ft/d) for the Tongue River alluvium, 5.8 m/d (19 ft/d) for the Rosebud Creek unconsolidated material, 19.6 m/d (61 ft/d) for the Lame Deer Creek alluvium and 12.2 m/d (40 ft/d) for the unconsolidated material in the Muddy Creek Valley. The values for the tributaries of Muddy and Lame Deer Creeks are similar to the 13.1 m/d (43 ft/d) hydraulic conductivity measured in similar material about 43 km (27 mi) to the southeast of the Reservation (BLM, 1977).

Calculated hydraulic conductivity values for the larger alluvial deposits of the Tongue River and Rosebud Creek on the Reservation are smaller than hydraulic conductivities estimated for alluvial deposits on the Tongue River, south of the reservation, and on other alluvial materials in the area. It was estimated in the environmental statement for the Decker expansion (USGS and MDSL, 1977) approximately 29 km (18 mi) to the south, that the alluvium of the Tongue River has a hydraulic conductivity range of 15.2 to 30.5 m/d (50 to 100 ft/d), although no tests were performed. Analyses of aquifer tests on the unconsolidated material for Pryor Creek, the Big Horn River and the Little Big Horn River to the east have yielded hydraulic conductivity values of 1,271 m/d (4,170 ft/d), 18.3 m/d (60 ft/d) and 6.7 m/d to 9.5 m/d (22 to 31 ft/d), respectively (McGill, Personal communication, 1978). Three USGS aquifer tests of the terrace material of the Little Big Horn River yielded an average hydraulic conductivity value of 57.0 m/d (187 ft/d) (Moulder, et al., 1960).

It is believed that hydraulic conductivity calculated from drillers' test data for the Rosebud Creek and Tongue River unconsolidated material are lower than actual values. In an attempt to check the pump test hydraulic conductivity values, data on groundwater seepage to each stream as developed from stream gaging measurements (see CHAPTER 7) were used to determine groundwater out-flow from a known cross-sectional area under measured hydraulic gradients. This method yielded a hydraulic conductivity value of 18.6 m/d (61 ft/d) for the Tongue River alluvium and 5.2 m/d (17 ft/d) for the unconsolidated material of Rosebud Creek.

Tongue River Member Hydrostratigraphic Unit

Anderson Unit

Three NCRP development tests in the Anderson coal and 12 plug test of the overlying sandstone, shale, and limy shale were used to estimate the hydraulic conductivity of the Anderson Unit. Analyses of short term pump testing of the Anderson coal gave an average hydraulic conductivity of 0.07 m/d (0.23 ft/d). Plug test of inter-bedded fine sandstones and shales overlying the coal indicated hydraulic conductivities that were an order of magnitude lower than the coal, and vertical conductivities that were 100 times smaller. This suggests that sandstone, siltstone, and shale of the Anderson Unit have low conductivities and can act as confining units. However, fractures probably exist which greatly increase field hydraulic conductivity. Review of tests reported on drillers' logs for wells finished in sandstone and shale yielded an average hydraulic conductivity value of 1.2 m/d (4 ft/d). Stratigraphically the Dietz coal beds are part of the Anderson Unit. Van Voast (1974) and Van Voast and Hedges (1975) report hydraulic conductivities averaging 1.2 m/d

(3.3 ft/d) for the Dietz coal in the Decker area to the south.

Based on available data and NCRP testing, 0.07 m/d (0.12 ft/d) and 1.2 m/d (4 ft/d) are assumed to be representative hydraulic conductivities for the Anderson coal and overlying sandstone and shale of the Anderson Unit, respectively.

Knobloch Unit

Hydraulic parameters were determined for the Knobloch Unit from four NCRP development tests on the Knobloch coal, two on the Pawnee coal, 10 plug tests of selected cores of sandstone, siltstone and shale, and three drillers' tests on a combination of coal and sandstone. The average hydraulic conductivity derived from four NCRP tests was 0.61 m/d (2 ft/d). A BLM conducted pump test on the Knobloch Coal at a site 14 km (9 mi) east of the Reservation yielded a hydraulic conductivity of 0.15 m/d. One test of the Pawnee coal seam gave a hydraulic conductivity of 1.5 m/d (5 ft/d). The second test, conducted on the unconfined coal overlaid by sand and gravel, gave a hydraulic conductivity of 1.8 m/d (6 ft/d). A pump test conducted on the Canyon coal seam in a BLM study area to the southeast of the reservation yielded a hydraulic conductivity of 0.6 m/d (2 ft/d)(BLM, 1977).

Plug test of sandstone and shales overlying the Knobloch coal showed that horizontal and vertical permeabilities were two to three orders of magnitude smaller that that of the coal. Fracturing of these materials increases their field permeabilities. Results of a test on a fractured shale plug yielded a hydraulic conductivity value of 2.2 m/d (7.3 ft/d). Evaluation of drillers' development tests on combinations of sandstone and underlying Pawnee and Sawyer coal beds yield hydraulic conductivity values of 0.04 m/d (0.12 ft/d) and 1.2 m/d (5 ft/d), respectively.

Average hydraulic conductivities of .61 m/d (2 ft/d), .80 m/d (2.6 ft/d), 1.2 m/d (4 ft/d), 1.7 m/d (5.5 ft/d), and .60 m/d (2 ft/d) are assumed to be representative of actual hydraulic conductivities in the Knobloch coal, Sawyer coal, interbedded sandstone and shale of the Knobloch unit, Pawnee coal, and Canyon coal respectively.

Clinker

Clinker forms a major portion of the consolidated hydrologic units found on the Reservation. It is believed that because the mode of formation and parent material of the clinker are similar in each hydrogeologic unit, hydrologic characteristics of the clinker are similar. One NCRP development test and three tests recorded in driller's logs were available for analyses. An NCRP test in the Anderson Clinker yielded a hydraulic conductivity of 0.04 m/d (0.1 ft/d). Evaluation of driller's development tests of clinker overlain by sand and gravel and sandstone yielded a range of values of 0.91 to 2.1 m/d (3 to 7 ft/d). Though clinker forms a major part of the hydrogeologic system in most of southeastern Montana, there are no data available from accurate pump tests. Van Voast and Hedges (1975) estimated that hydraulic conductivity values for clinker in the Decker area, south of the Reservation, range from 46.0

to 61.0 m/d (150 to 200 ft/d). Rahn (1976) reported clinker to be a good aquifer and noted that records of a 24-hour pump test of clinker during the construction of I-90 near Gillette, Wyoming indicated a hydraulic conductivity of 73.5 m/d (241 ft/d). However, recent pump test conducted in coal in the same region have also indicated clinker can act as a boundary condition of low permeability (Hardaway, personal communication, 1978).

It is hypothesized that the range of hydraulic conductivities from 0.04 m/d (0.1 ft/d) to 73.5 m/d (241 ft/d) may reflect a permeability zonation which occurs during clinker formation. As a coal seam burns, underlying sandstone and shale begin to alter. It is believed that initial changes are the hardening and eventual melting of adjacent and overlying shale units and the oxidation of iron in the sandstone. This process would probably reduce existing hydraulic conductivities. As the coal burns, ash is formed and shale and other impurities, such as pieces of overlying rock which fall into the burning coal, form coal clinker which collects at the base of the void as a rubble zone. It is believed that the thicker the coal, and the more shale partings and other impurities, the larger the volume of highly vesicular coal clinker that would accumulate. The collapse fractures the overlying material and creates a fracture permeability which may be less than, equal to, or more than the original permeability. If significant accumulations of coal clinker relative to coal ash are present, the basal zone will probably have a higher hydraulic conductivity than the preclinker deposits which appear to contain a basal zone which is highly porous and vesicular in nature. The altered shale and sandstone close to the original upper surface of the coal are usually highly fractured with the degree of fracturing decreasing somewhat as the burn is traced upward and the rocks are less altered, maintaining more of their original properties.

Low hydraulic conductivity measurements for clinker may be the result of well emplacement in a clinker composed of slightly altered shale or sandstone, or a basal zone with a small degree of coal clinker. High hydraulic conductivity measurements could result from tests on large basal coal-clinker rubble zones or highly fractured shale and sandstone units. Without a large number of pump tests on clinker on the Reservation, a representative hydraulic conductivity for clinkers cannot be derived. The hydraulic conductivity can be calculated if the rate of flow of water through a measured cross-sectional area of clinker and the hydraulic gradient are known. This method was used to estimate the hydraulic conductivities of the Anderson and Knobloch clinker. Values of 5.4 m/d (17.7 ft/d) and 11.1 m/d (36 ft/d) were obtained, respectively. It is assumed that these numbers are representative of the general range of values for clinker in the region. A specific yield of 0.1 has been assumed as representative of the deposit because of the fractured and unconfined nature of the clinker.

Lower Tongue River Member Hydrogeologic Unit

Pump test data from the Lower Tongue River Member Unit included results from NCRP aquifer tests on two wells finished in the McKay coal; two on local coals and one on the Robinson coal; 17 tests reported in drillers' logs of the Rosebud and McKay coals plus overlying or underlying materials; 72 tests on sandstones found in the major stream valleys; and seven plug tests of sandstone, siltstone and shale. Analyses of development tests yielded an average hydraulic conductivity of 3.5 m/d (11 ft/d) for the McKay coal, 0.24 m/d (0.8 ft/d) for the Robinson coal and 2.7 m/d (9 ft/d) for local seams below the Rosebud coal. Average values reported by Van Voast (1977) were 4.3 m/d (13.8 ft/d) for the Rosebud coal and 0.5 m/d (1.5 ft/d) for the McKay coal at Colstrip, 21 km (13 mi) north of the Reservation. At the Westmoreland Sarpy Creek mine 10 km (6 mi) northwest of the Reservation, the BIA (1976) reported hydraulic conductivities of 0.04 m/d (0.13 ft/d) for the McKay seam, 0.57 m/d (1.9 ft/d) for stray coal above the Rosebud coal, and a range of values of 0.01 to 1.4 m/d (0.04 to 4.7 ft/d) for the Robinson coal. Sandstone members of the Lower Tongue River unit found along the major stream valleys are used as domestic supplies of water. Analyses of pumping information reported on drillers' logs yielded hydraulic conductivity values of 6.4 m/d (21 ft/d) in the Muddy Creek area, 8.2 m/d (27 ft/d) in the Lame Deer Creek Valley, 7.3 m/d (24 ft/d) in the Rosebud Creek area, and 9.2 m/d (30 ft/d) in the Tongue River Valley. A plug test on a weathered sandstone and siltstone in the Sarpy Creek area yielded a hydraulic conductivity of 17.1 m/d (56.2 ft/d). NCRP plug tests, and plug tests done at the Sarpy Creek - Westmoreland Mine (BIA, 1976) indicated that unweathered sandstone, siltstone and shale have hydraulic conductivities which range from 0.6×10^{-6} to 0.3 m/d (2.2×10^{-6} to 1.0 ft/d).

Hydraulic conductivity values of 1.8 m/d (6 ft/d), and 7.9 m/d (26 ft/d) are assumed to be representative of the hydraulic conductivities of the Rosebud coal, McKay coal, and Robinson coal; and sandstone and undifferentiated sandstone and shale of the Lower Tongue River Member Unit.

MOVEMENT OF GROUNDWATER

Groundwater moves from the southwest and northeast of the highland of the Central Reservation area and from the Sarpy Mountains in the northwest corner of the Reservation, toward Rosebud Creek and the Tongue River. Recharge from direct precipitation and spring snow melt enter the regional groundwater system in relatively flat areas (such as stream valley bottoms and the central highland area) and in areas with extensive clinker deposits, like the Divide Clinker Plateau and Tongue River Knobloch clinker. Shallow groundwater discharges as springs in the higher country, along Rosebud Creek and in the Tongue River and its major tributaries (Figure 6.9).

Hydrographs of 76 wells for the 1976 and 1977 water years were evaluated in an attempt to quantify the amount of recharge to aquifer systems and the relation of increases in storage to precipitation. A summary of this evaluation is presented in Table 6.5. Analyses of the data indicated that the highest percentage of recharge was to the Unconfined Unit located in the valleys of the Tongue River and Rosebud Creek. Knobloch clinker, bordering the alluvium in the Tongue River Valley, and the fine grained sandstones contained within the Rosebud Creek Valley, received the second and third most recharge, respectively. The Unconfined Knobloch Unit sandstones received even less recharge. The Unconfined Anderson, Knobloch, and Lower Tongue River Member coals showed progressively smaller amounts of recharge. Confined Anderson and Knobloch, and Lower Tongue River Unit coal received little if

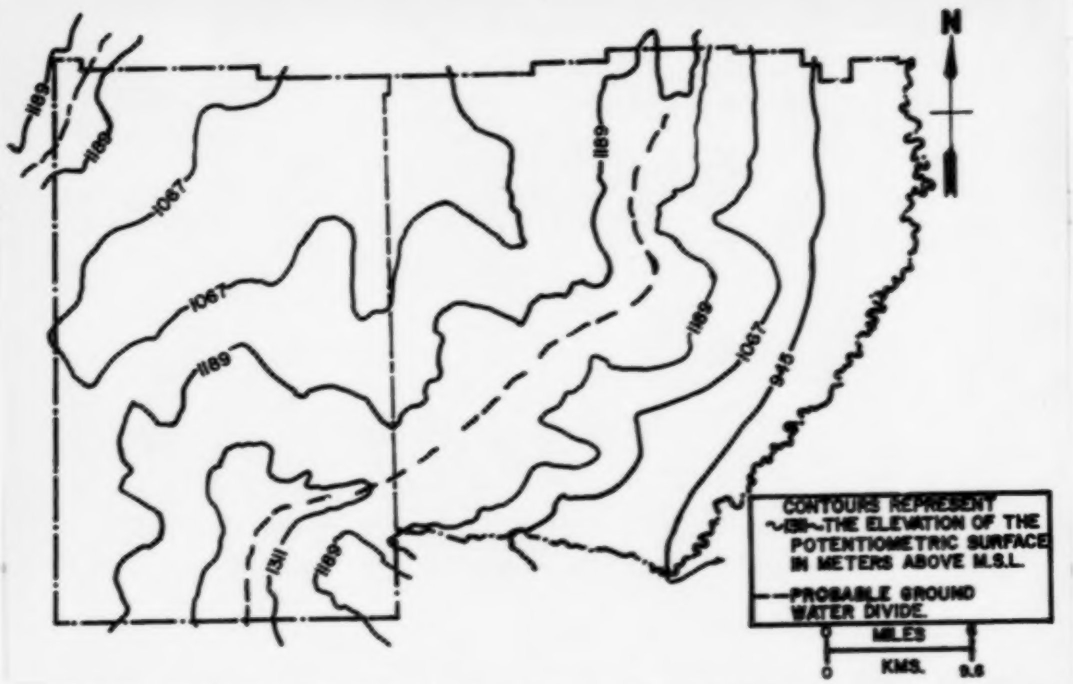

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Figure 6.9. Generalized potentiometric surface on the Reservation.

TABLE 6.5. SUMMARY OF RECHARGE DATA

Aquifer Material	Unit name u=unconfined c=confined	Specific Yield	Average Recharge 10/75 - 9/76 meters	Average Recharge 10/75 - 9/76 feet	Average Recharge 10/76 - 9/77 meters	Average Recharge 10/76 - 9/77 feet	Percent of Total Precipitation at Lane Deer, Mt. 10/75 - 9/76 0.51m (1.66 ft)	Percent of Total Precipitation at Lane Deer, Mt. 10/76 - 9/77 0.37m (1.23 ft)	Principal Periods of Recharge 10/75-9/76	Principal Periods of Recharge 10/76-9/77
Sand and Gravel	Unconsolidated Rosebud Creek Valley (u)	0.15	0.07	0.23	0.07	0.23	14	19	January to May	February to May
	Tongue River Valley (u)	0.12	0.08	0.26	0.07	0.22	16	17	December to June	October to June
Sandstone	Anderson Unit* (c)	0.00003	-	-	0.00002	0.00006	-	0.005	-	November to May
	Wall Unit* (c)	0.00003	-	-	0.00009	0.0003	-	0.024	-	November to April
	Knobloch Unit (u)	0.01	0.0006	0.002	0.003	0.009	0.12	0.73	February to June	November to May
	Lower Tongue River Member Unit (u)	0.01	0.0006	0.019	0.006	0.02	1.14	1.63	January to May	January to May
Clinker	Knobloch Unit (u)	0.10	-	-	0.03	0.1	-	8.1	-	April to January
Coal and Shale	Anderson Unit* (u)	0.01	-	-	0.005	0.017	-	1.4	-	July to September
	Anderson Unit (c)	0.00005	-	-	0.0002	0.007	-	0.06	-	October to June
	Knobloch Unit (u)	0.01	0.005	0.02	0.002	0.008	1.21	0.65	March to September	March to April
	Knobloch Unit (c)	0.00005	-	-	0.00005	0.00015	-	0.012	-	March to June
	Lower Tongue River Member Unit (u)	0.01	-	-	0.002	0.008	-	0.65	-	December to June
	Lower Tongue River Member Unit (c)	0.00001	-	-	0.00001	0.00003	-	0.002	-	November to June

*Only one hydrograph was available.

any recharge during the 1976 and 1977 water years. The aquifers tend to recharge from October through June. Late fall rains, winter thaws, spring melts, and spring rains appear to provide the main pulses of recharge to the unconfined and confined aquifer systems.

The small rates of recharge to the confined aquifer systems on the Reservation indicate that the moisture available in the 1975 and 1976 water years may not have reached the deeper flow systems during the time of observation. This indicates that the stacked systems within the Tongue River Member receive recharge through a much slower process of downward leakage from overlying systems of greater hydrologic potential (Figure 6.10). Though there is a slight southeasterly dip to the rock units, it is hypothesized that a vertical no-flow boundary exists in the central region and that water moves away from the central area towards Rosebud Creek and the Tongue River. Topography is apparently the controlling factor affecting shallow groundwater movement on a Reservation-wide basis.

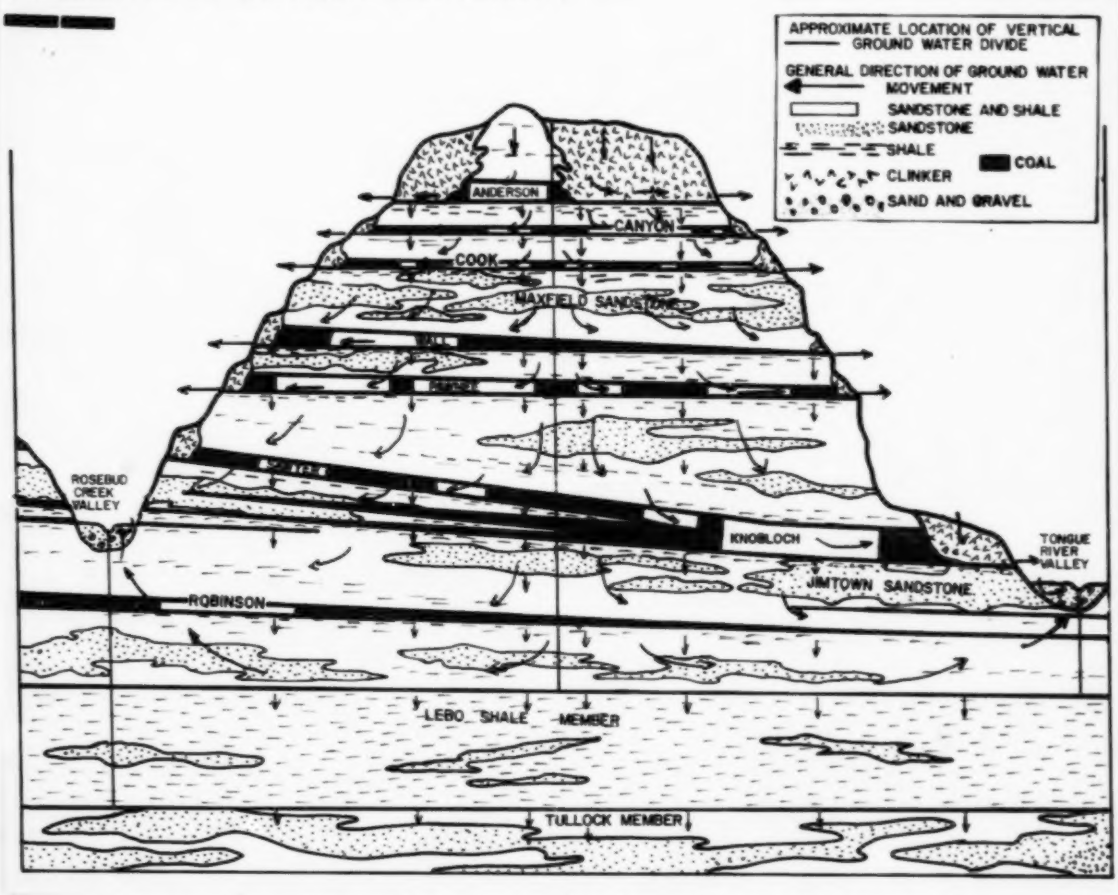

APPROXIMATE LOCATION OF VERTICAL GROUND WATER DIVIDE
GENERAL DIRECTION OF GROUND WATER MOVEMENT
SANDSTONE AND SHALE
SANDSTONE
SHALE
COAL
CLINKER
SAND AND GRAVEL
ANDERSON
CANYON
COOK
MAXFIELD SANDSTONE
ROSEBUD CREEK VALLEY
KNOBLOCH
TONGUE RIVER VALLEY
JIMTOWN SANDSTONE
ROBINSON
LEBO SHALE MEMBER
TULLOCK MEMBER

Figure 6.10. Generalized cross-section of the central portion of the Reservation.

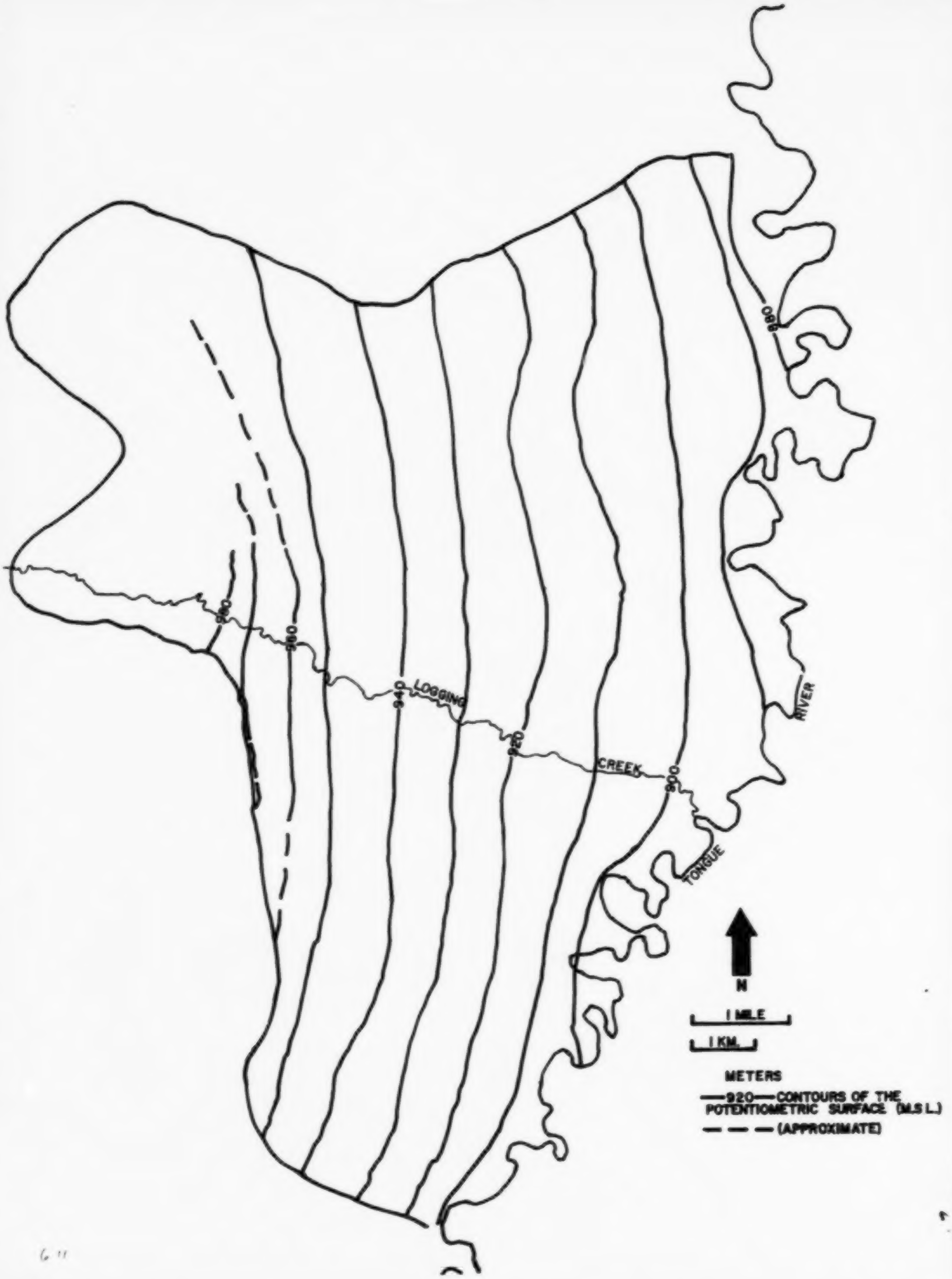
Thick continuous coal seams like the Anderson, Canyon, Wall, Sawyer, Knobloch, Rosebud, and McKay transmit water laterally towards outcrop areas. Outcrop areas of aquifers in the central portion of the Reservation are usually discharge points if sufficient water is available. In some areas near the outcrop, part of the discharge may move vertically through fractures, recharging underlying aquifers. Part or all of the remaining water may be lost through evapotranspiration. It has been reported by researchers conducting detailed site specific investigations (Van Voast, 1974; Van Voast and Hedges, 1975) that faulting can act as barriers to flow. Faulting does occur with displacements of up to 18 m (60 ft) and probably influences groundwater movement locally. The Lebo Shale Member of the Fort Union Formation likely separates the underlying hydrogeologic units from the Tongue River Member Units.

Logging Creek Priority Study Area

The Logging Creek Priority Study Area is located in the Tongue River Valley (Figure 5.28) and includes the sandstones and coals of the Knobloch Unit, the Lower Tongue River Member Unit, and the Tongue River alluvium. The Knobloch coal ranges from 9 to 20 m (30 to 65 ft) in thickness and is the major strippable coal in the valley. Information from 15 wells located within the study area and additional wells in the Tongue River Valley provide geologic and hydrologic data for the study area. Figure 6.11 presents a potentiometric contour map of the Knobloch coal seam, clinker and Tongue River unconsolidated material. Evaluation of data for this priority site indicates the Knobloch Unit is probably being recharged by downward leakage of water in the high plateau region to the west, by limited leakage from the Logging Creek and Stebbins Creek alluvium, and directly by precipitation on clinker and alluvium.

Figure 6.12 shows a partial cross-section of the Logging Creek Priority Area and the approximate position of the potentiometric surface for the coal-clinker alluvial flow system. The confined flow system operating in the coal apparently becomes unconfined near the clinker-coal boundary. In most of the area, the Knobloch coal is above the alluvial valley. It is assumed that groundwater in the clinker flows out as springs at the easternmost outcrop, runs down slope and reenters the alluvial material, and/or enters the clinker zone, and flows vertically through the fractured baked shale into underlying sandstone and shale deposits connected directly to the alluvium system. Evaluation of water levels from wells NCRP 29B, NCRP 8B and from the presence of water in both Logging Creek and Stebbins Creek indicated that an unconfined ground-water system is operating above the confined system. However, the limited data available preclude preparation of an additional potentiometric surface. In the lower reach, Stebbins Creek becomes influent and disappears close to the coal-clinker contact. Logging Creek continues to flow across the clinker coal boundary near its mouth. It is believed that the Logging Creek stream bed is partially sealed by fine material, and that the stream is temporarily perched above the lower clinker water table.

An input/output model of the coal-clinker-alluvium flow system operating in the Logging Creek area was prepared to further delineate the recharge-discharge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960
940
LOGGING
920
CREEK
900
TONGUE
RIVER
880
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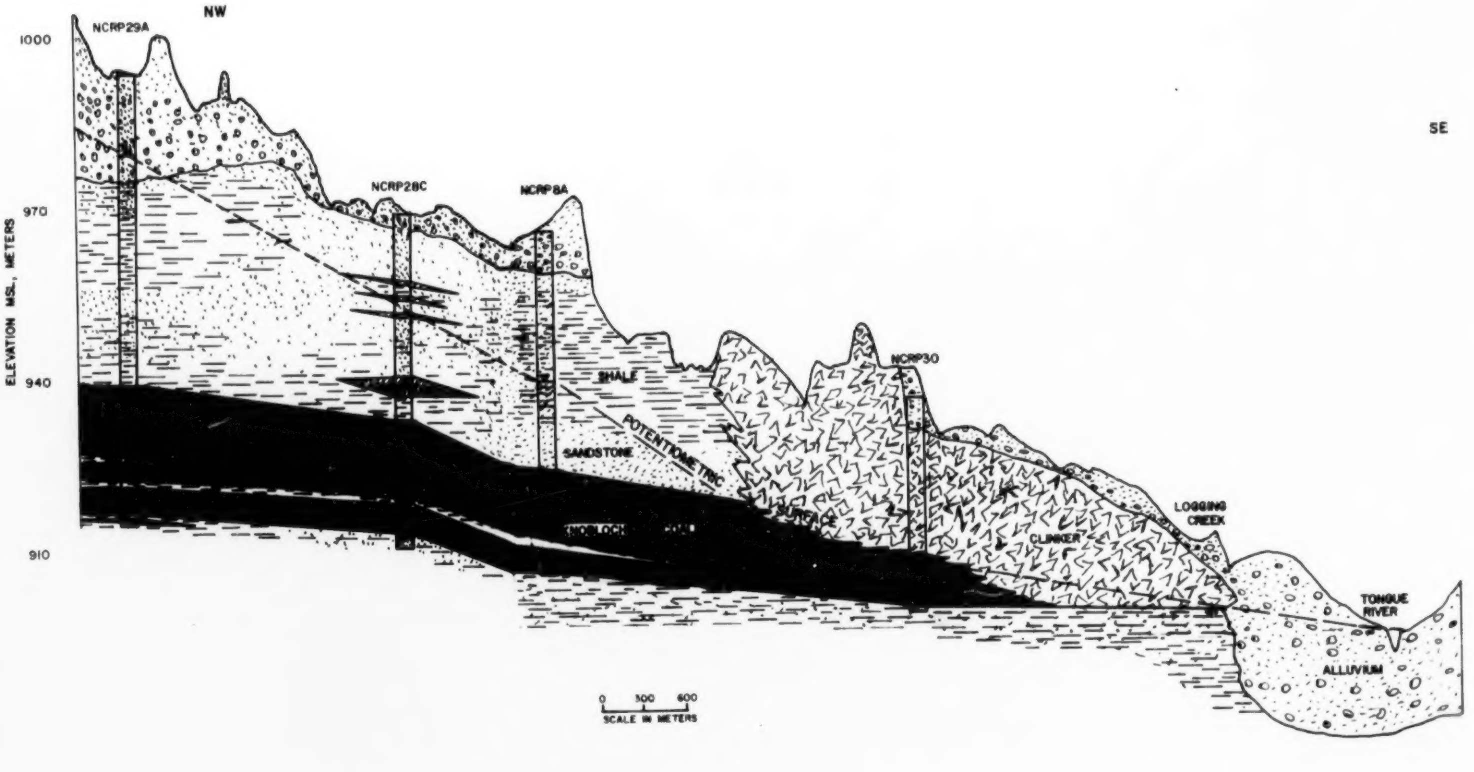
— — — (APPROXIMATE)

Figure 6.11. Potentiometric contour map of the Knobloch coal seam, clinker and alluvium flow system, Logging Creek Priority Study Area.


NCRP29A
NW
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NCRP8A
NCRP30
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ELEVATION MSL, METERS
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SANDSTONE
POTENTIOMETRIC SURFACE
KNOBLOCH COAL
CLINKER
LOGGING CREEK
TONGUE RIVER
ALLUVIUM
0 300 600
SCALE IN METERS

Figure 6.12. Cross-section of the Logging Creek Priority Study Area indicating potentiometric surface.

components of the near-surface flow system (Figure 6.13). The model represents groundwater movement through a volume of coal, clinker, underlying shale and sandstone, and alluvium 1,000 m (3,280 ft) in length perpendicular to the direction of groundwater flow. The area modeled extended from 3,541 m (11,616 ft) west of the coal-clinker boundary to the Tongue River. The average thickness of the units, and simplified unit boundaries and width were defined.

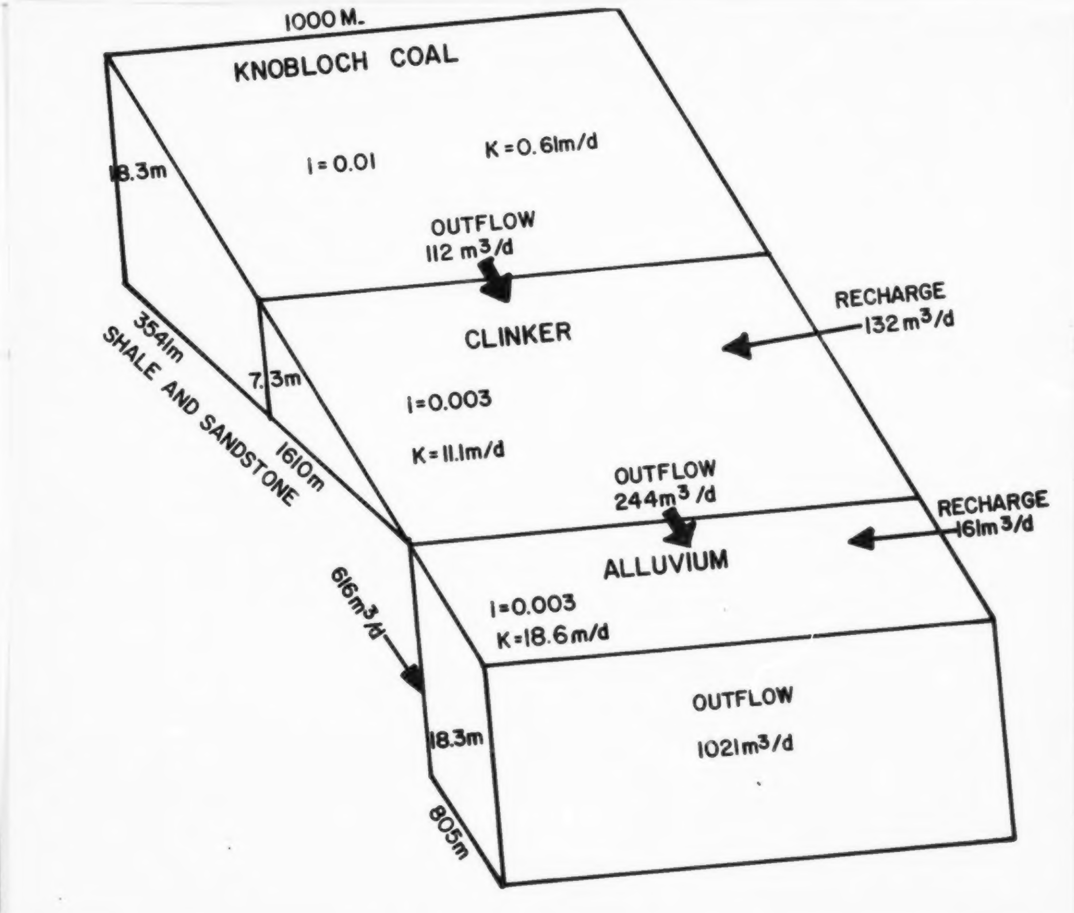
1000 M.
KNOBLOCH COAL
18.3m
I = 0.01
K = 0.61m/d
OUTFLOW
112 m3/d
RECHARGE
132 m3/d
CLINKER
3541m
SHALE AND SANDSTONE
7.3m
I = 0.003
K = 11.1m/d
1610m
OUTFLOW
244m3/d
RECHARGE
161m3/d
ALLUVIUM
616m3/d
I = 0.003
K = 18.6 m/d
OUTFLOW
1021m3/d
18.3m
805m

Figure 6.13. Input-output model of the Logging Creek Priority Study Area groundwater system.

Well level data for wells finished in the Knobloch coal, clinker, and Tongue River alluvium were evaluated for water years 1976 and 1977 and average rates of recharge to each unit were determined (Table 6.5). Analyses of water level fluctuation data for the wells finished in the Knobloch coal indicated the confined system was not receiving significant recharge in the area. No recharge was assumed to occur directly to the Knobloch coal in the modeled area.

One dimensional groundwater flow was assumed to occur in the modeled area. Therefore groundwater flow is described by Darcy's Law:

$$Q = KiA$$

Where:

Q = rate of flow, m^3/d

K = hydraulic conductivity, m/d

i = hydraulic gradient, m/m

A = cross sectional area, m^2

However, it was noted that vertical flow probably occurs to some degree from the clinker zone to the alluvium and to underlying shale and sandstone units. This component was not calculated. Instead it was assumed for modeling purposes that water flowed through the clinker via horizontal flow. The calculated average unit thicknesses, hydraulic conductivities, and measured hydraulic gradients for each unit are presented in Figure 6.13.

Analyses indicated groundwater flows through a 1,000 m (3, 280 ft) long cross section of coal at a rate of 112 m^3/d (3,955 ft^3/d) and enters the unconfined clinker unit. This water then moves into the clinker unit where 132 m^3/d (4,651 ft^3/d) of recharge is added to the groundwater flow. Clinker outflow to the alluvial unit is calculated to be 244 m^3/d (8,617 ft^3/d). It was assumed for the purposes of the model that all this water reaches the alluvial zone and that losses due to evapotranspiration are negligible. The hydraulic gradient, cross-sectional area, recharge and rate of outflow to the Tongue River were calculated for the alluvial unit from seepage data (Refer to CHAPTER 7, SURFACE WATER). Inflow-outflow evaluation of the alluvial zone showed an additional 616 m^3/d (21,753 ft^3/d) of groundwater entering the alluvium. This component of inflow was attributed to a massive sandstone unit with shale partings in direct contact with the alluvium underlying the coal-clinker system. At least eight domestic wells are completed in sandstone below the Knobloch unit in the Tongue River Valley.

The hydraulic conductivity of the sandstone unit was calculated to be 11.2 m/d (56.7 ft/d) by assuming a cross-sectional area of 1000 m by 18.3 m, a hydraulic gradient of 0.003 for an unconfined system as measured in the clinker and alluvium, and an outflow of 616 m^3/d (21,753 ft^3/d). This hydraulic conductivity value corresponds fairly well with the average value of 8.2 m/d (26.9 ft/d) for massive sandstones of the Lower Tongue River Member Unit observed in the Rosebud Creek Valley Area.

It is believed that the flow system defined in the Logging Creek Priority Study Area is typical of the hydrologic system operating in the Tongue River Valley. Groundwater flow is generally from west to east discharging to the Tongue River. It is believed that a similar system, which is recharged in the highland in Custer National Forest to the East of the Tongue River, flows principally through the Knobloch coal seam to the west and discharges into the Tongue River.

Buffalo Jump Priority Study Area

The Buffalo Jump Priority Study Area is located in the central highland of the Reservation (Figure 5.31) and contains the sandstones, local coals, and Anderson coal and clinker of the Anderson Unit. Information from 7 NCRP completed wells and numerous springs provided geologic and hydrologic data for the study area (Figure 6.14). Analyses of data indicate that the Anderson coal is recharged in the central portion of the area and that groundwater moves to the northwest and southeast discharging along clinker-shale contacts in numerous valleys. Figure 6.15 shows a cross section of the Priority Study Area and the approximate position of the potentiometric surface. The confined system operating in the coal becomes unconfined near the clinker-coal boundary and remains unconfined in the clinker. Springs found at elevations over 30 m (100 ft) above the top of the Anderson coal indicate that a shallow near surface unconfined flow system is also present. Some of these springs were observed to emanate from the base of the Smith coal seam. However, during drilling a noticeable zone of saturation was not encountered. The low hydraulic conductivity of the shale underlying both the clinker and the coal permits limited downward migration of the groundwater. A significant quantity of water probably moves gradually downward to recharge the deeper underlying aquifer systems.

An input-output model of the coal-clinker flow system operating in the Buffalo Jump Area was prepared to further delineate the recharge-discharge components of the near surface flow system and to quantify the rate of groundwater movement through the system (Figure 6.16). The model represented groundwater movement through a volume of coal and clinker 1,000 m (3,280 ft) in length perpendicular to the direction of groundwater flow. The area modeled extended from 1,610 m (5,280 ft) west of the coal clinker boundary to B.Hart Spring which flows from the base of the clinker unit. The average thicknesses of units and simplified unit boundaries and widths are presented in Figure 6.16.

Well level data for wells finished in the Anderson coal were evaluated and less than 0.005 m/y (0.017 ft/y) of recharge was recorded. Because the recharge rate to the unit is probably very small, only groundwater outflow components were indicated for the model. Recharge to the clinker was estimated from water level fluctuations in wells in the Anderson and Knobloch clinker to be 0.031 m/y (0.1 ft/y).

Calculation of the rate of groundwater flow through the model utilized techniques identical to those described for the Logging Creek Priority Area. Groundwater flows through a 1,000 (3,280 ft) long cross section of coal at a rate of 18.5 m^3/d (653 ft^3/d). This flow then enters the clinker zone where 161 m^3/d (5,280 680 ft^3/d) of recharge is added to the groundwater flow. These calculations indicate a total of 179.5 m^3/d (865 ft^3/d) is available for spring discharge. A total of 24.5 m^3/d (865 ft^3/d) of water was measured discharging from B.Hart Spring located at the eastern boundary of the model. Some water also discharges to other springs in the area and some water moves downward, recharging underlying formations. Using 179.5 m^3/d (6,399 ft^3/d) as the available flow to springs and possible losses to deep percolation, the hydraulic conductivity of the clinker was calculated to be 5.4 m/d (17.7 ft/d).

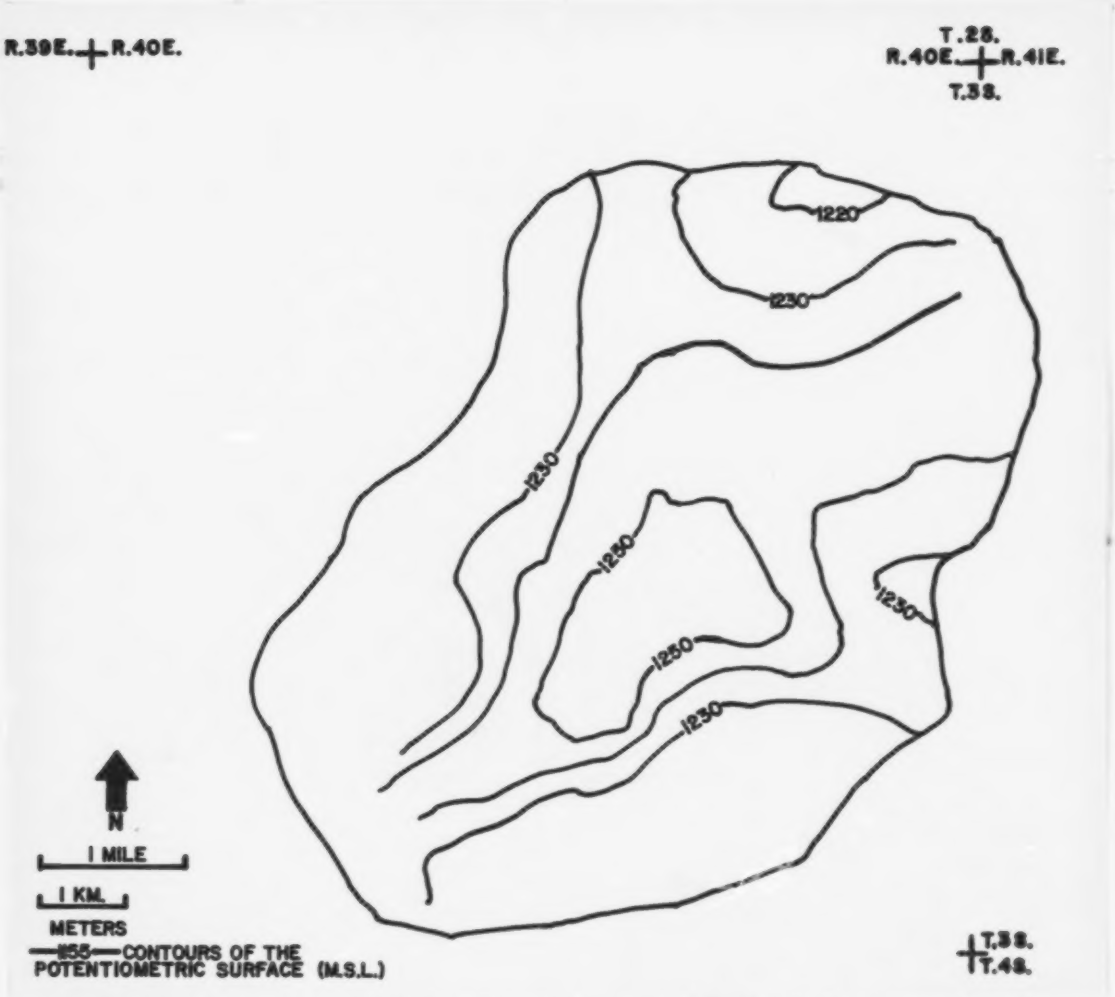
R.39E.
R.40E.
T.2S.
R.40E.
R.41E.
T.3S.
1220
1230
1230
1230
1250
1250
1230
1230
N
1 MILE
1 KM.
METERS
1155 CONTOURS OF THE POTENTIOMETRIC SURFACE (M.S.L.)
T.3S.
T.4S.

Figure 6.14. Potentiometric contour map of the Anderson coal and clinker flow system.

The Buffalo Jump Priority Study Area is typical of the central highlands of the Reservation. To the west of the Priority Area less clinker is present. The main flow system is a confined system. To the north and east of the Priority Area most of the Anderson coal is burned and thick deposits of clinker cover the entire highland. This large expanse of the Anderson Aquifer is directly recharged by precipitation and snow melt. Numerous springs emanate from the Anderson clinker-shale contacts. It is believed that the area of clinker to the east of the Priority site contains a large volume of water in its central portion. Some groundwater is available for downward migration and recharge of lower aquifer systems including the Knobloch coal aquifer system found in the Logging Creek Priority Study Area.

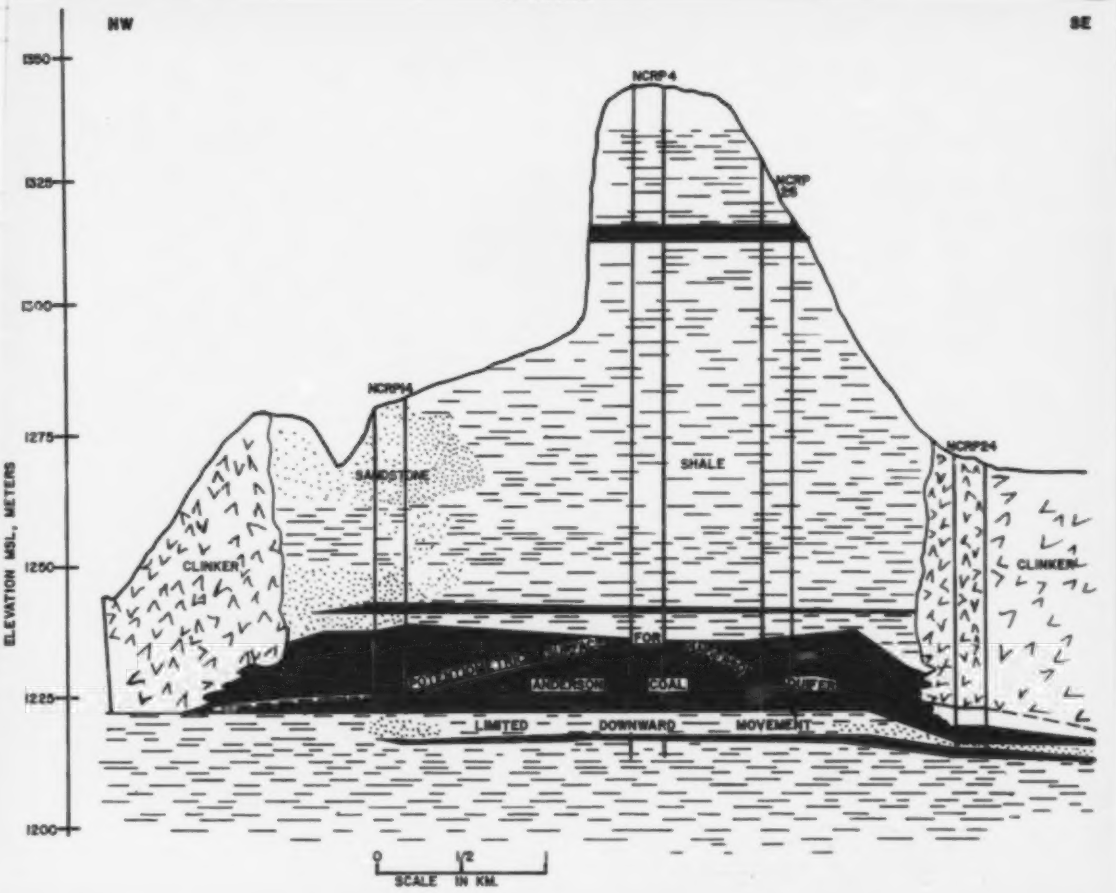
NW
SE
1350
1325
1300
1275
1250
1225
1200
ELEVATION MSL, METERS
NCRP4
NCRP 26
NCRP14
NCRP24
SANDSTONE
SHALE
CLINKER
CLINKER
POTENTIOMETRIC SURFACE
FOR
ANDERSON
COAL
AQUIFER
LIMITED
DOWNWARD
MOVEMENT
0
1/2
SCALE IN KM.

Figure 6.15. Geologic cross-section of Buffalo Jump area, showing potentiometric surface.

Indian Coulee Priority Study Area

The Indian Coulee Priority Study Area is located to the northeast of the Rosebud Creek and contains the sandstones and coals of the lower Tongue River Unit (Figure 5.34). Information from 10 NCRP completed wells located within the study area provided geologic and hydrologic data for the study area. In most of the study area, the Rosebud and McKay coal seams are not saturated. Potentiometric data (Figure 6.17) represent a composite surface of the shallow and confined aquifers operating in the area. Analyses of data indicate that water is recharged to the unconfined system directly by precipitation; and to the confined system by downward leakage and by recharge in the outcrop areas in the Sarpy Mountains to the northwest. Flow is from the northwest to the southeast with groundwater discharging into Rosebud Creek. Figure 6.18 shows a cross section of the Priority Area with the approximate position of the potentiometric surface. Extensive, thick occurrences of clinker are not present in this Study Area in contrast with the other two Priority Areas.

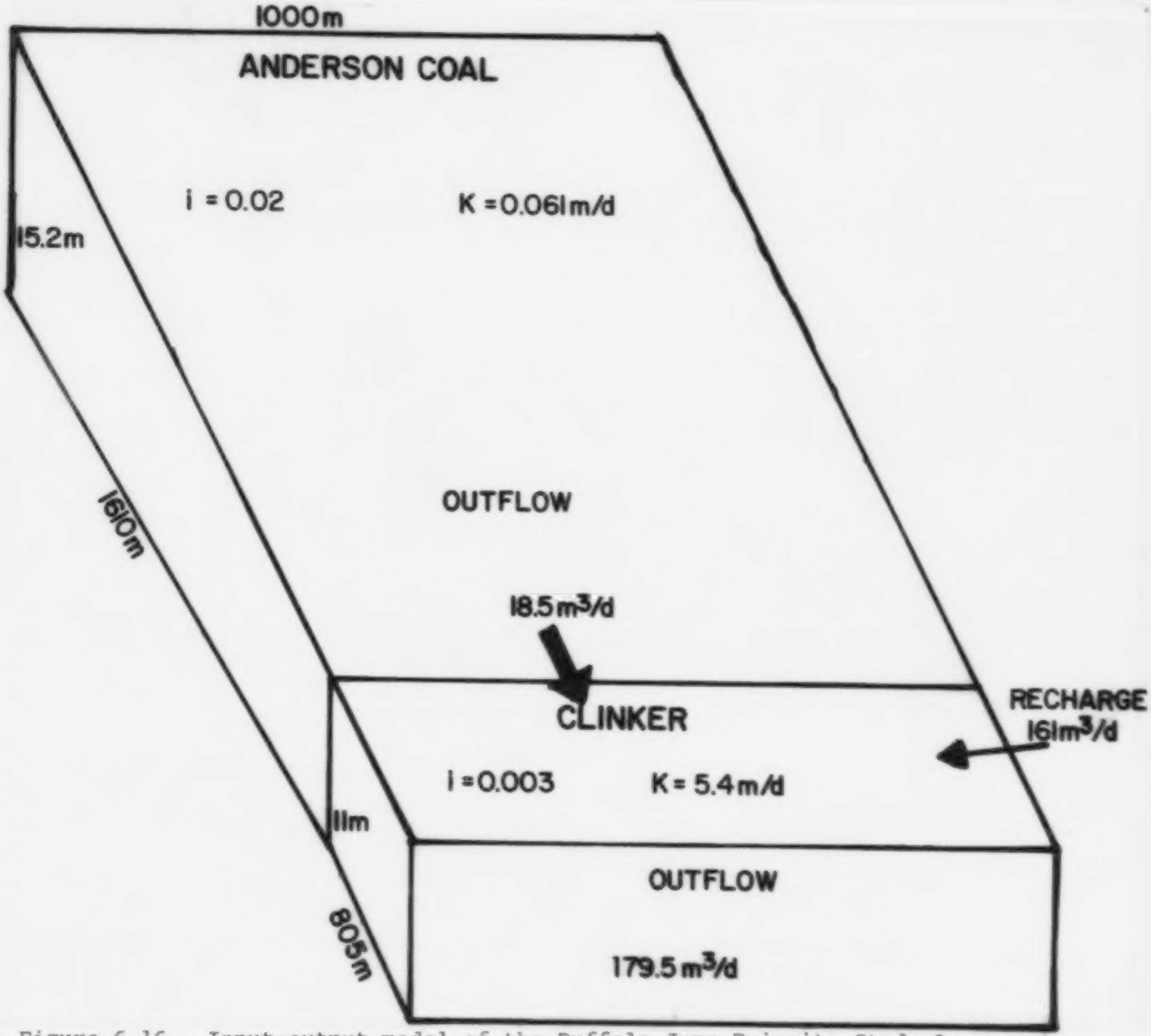
1000m
ANDERSON COAL
i = 0.02
K = 0.061m/d
15.2m
1610m
OUTFLOW
18.5m3/d
CLINKER
RECHARGE
161m3/d
i = 0.003
K = 5.4m/d
11m
OUTFLOW
805m
179.5m3/d

Figure 6.16. Input-output model of the Buffalo Jump Priority Study Area groundwater system.

Remnants of large clinker zones are present on the tops of a few of the higher hills in the area.

Well NCRP 35A was completed in the Robinson coal. Analyses of water level data collected at this well indicated that this basal coal of the Tongue River Member is saturated and confined. When water levels were compared with NCRP 35B, finished in the shallow unconfined system, it was evident that water in the confined system moves upward and discharges into Rosebud Creek.

An input-output model of the composite sandstone-shale-coal unit and Rosebud Creek alluvium flow system operating in the Indian Coulee area was constructed (Figure 6.19). However, hydrogeologic control was sparse in the study area. It was assumed that the model represented groundwater flow. The area modeled extended from 3,702 m (12,144 ft) northwest of the composite unit-alluvium unit boundary to Rosebud Creek. The average thickness of the

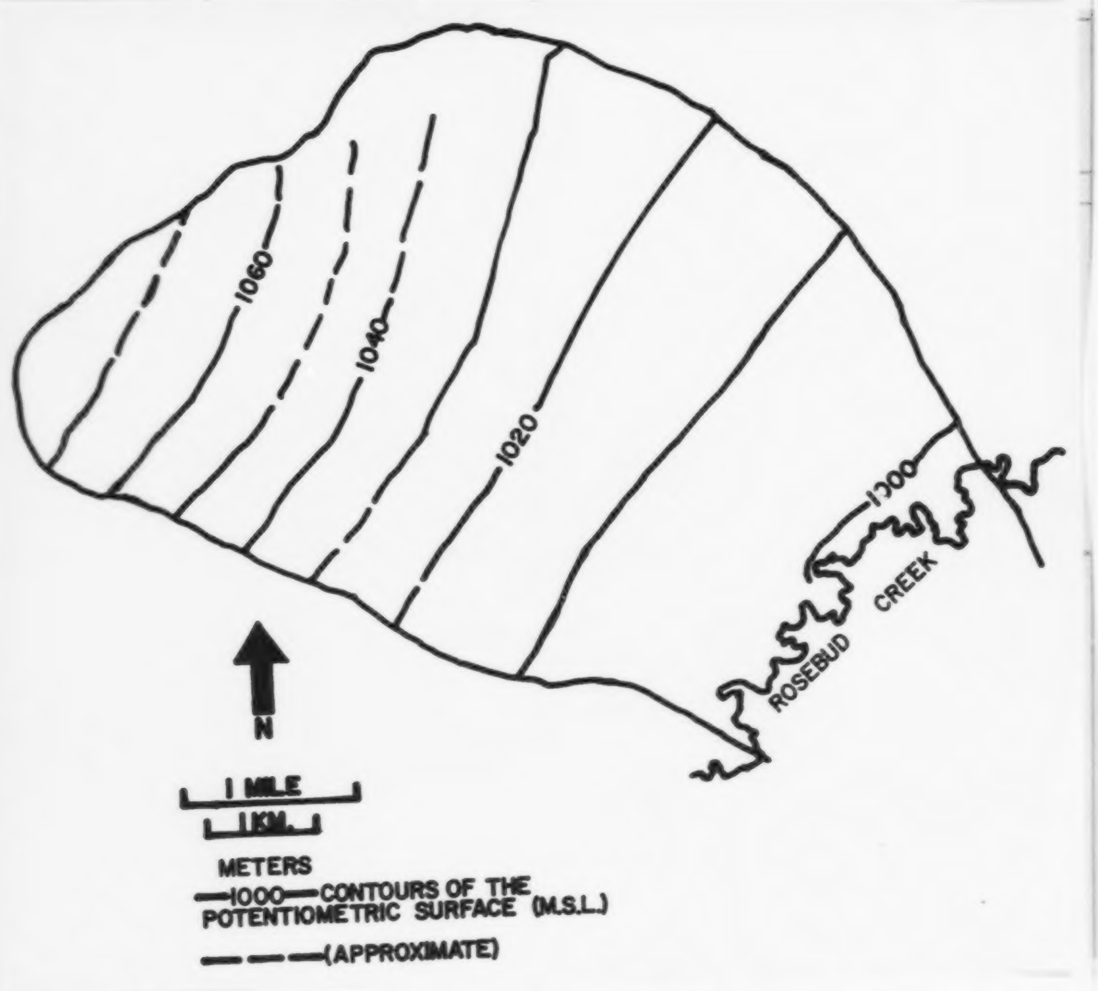
1060
1040
1020
1000
ROSEBUD CREEK
N
1 MILE
1 KM.
METERS
—1000— CONTOURS OF THE POTENTIOMETRIC SURFACE (M.S.L.)
— — —(APPROXIMATE)

Figure 6.17. Potentiometric contour map of the sandstone, shale, and coal flow system, Indian Coulee Priority Study Area.

units and simplified unit boundaries are presented in Figure 6.19.

It was calculated that recharge to the composite unit was less than 0.006 m/y (0.23 ft/y). Because recharge to this unit is very small, only a groundwater outflow component was calculated for the composite unit. Recharge to the alluvial material was calculated to be 0.

Outflow of groundwater from the alluvium was calculated to be 126.9 m^3/d (4,481 ft^3/d) from seepage data. The hydraulic conductivity of the alluvium was calculated to be 5.2 m/d (17 ft/d) using the measured outflow, hydraulic gradient and cross-sectional area. This value was surprisingly close to the 5.8 m/d (19 ft/d) calculated from available pump test data. The daily recharge rate to the alluvium was subtracted from the outflow rate to yield the rate of outflow from the composite aquifer to the alluvium. The 4.5 m^3/d (159

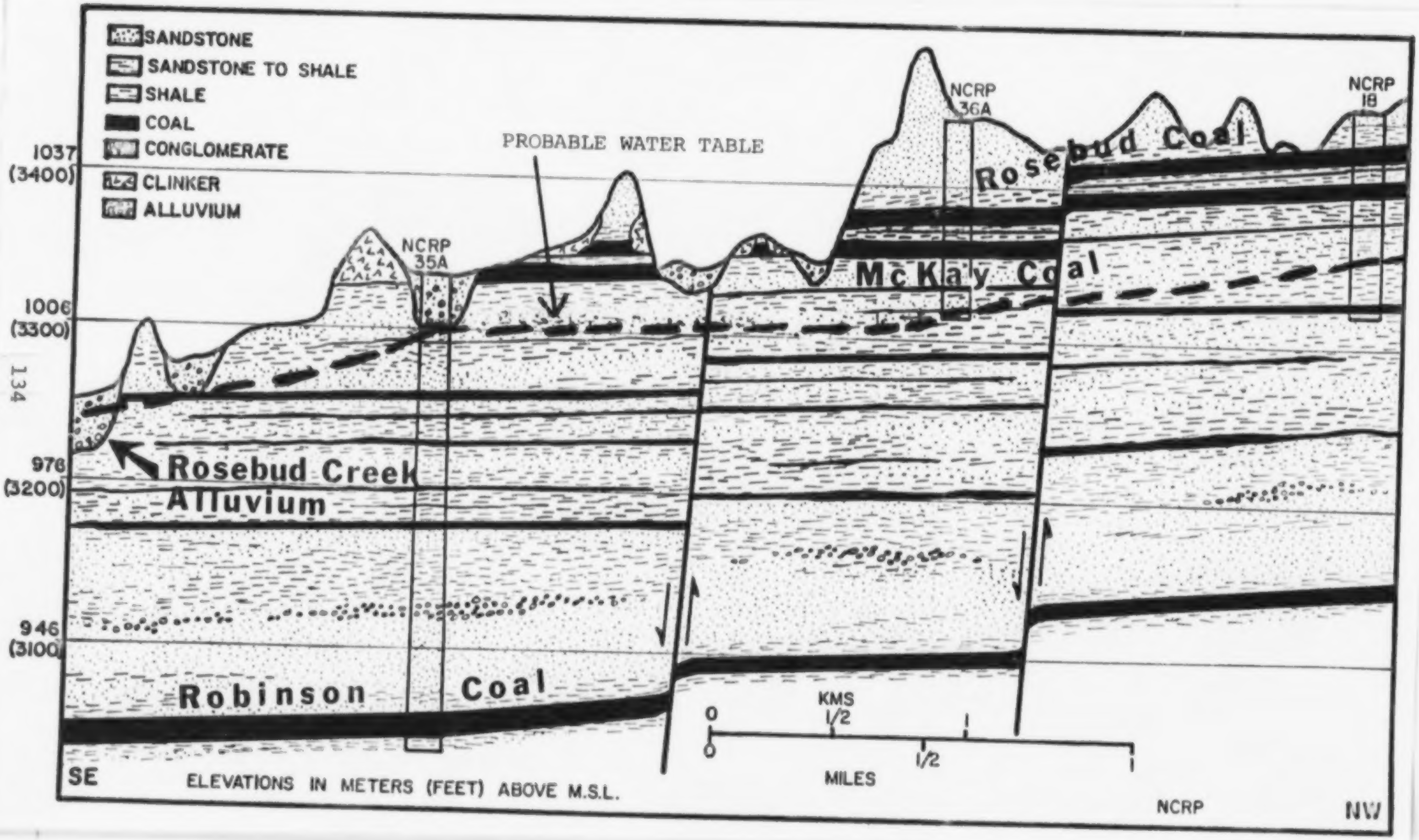
SANDSTONE
SANDSTONE TO SHALE
SHALE
COAL
CONGLOMERATE
CLINKER
ALLUVIUM
PROBABLE WATER TABLE
NCRP 35A
NCRP 36A
NCRP 18
Rosebud Coal
McKay Coal
Rosebud Creek Alluvium
Robinson Coal
1037 (3400)
1006 (3300)
976 (3200)
946 (3100)
SE
NW
ELEVATIONS IN METERS (FEET) ABOVE M.S.L.
KMS
0
1/2
1
MILES
NCRP

Figure 6.18. Cross-section of the Indian Coulee Priority Study Area, indicating approximate position of the potentiometric surface.

ft^3/d) outflow rate from the composite unit was then used to calculate the hydraulic conductivity utilizing an assumed saturated thickness of 13.7 m (45 ft). It was assumed that only the composite unit contributes inflow to the alluvium.

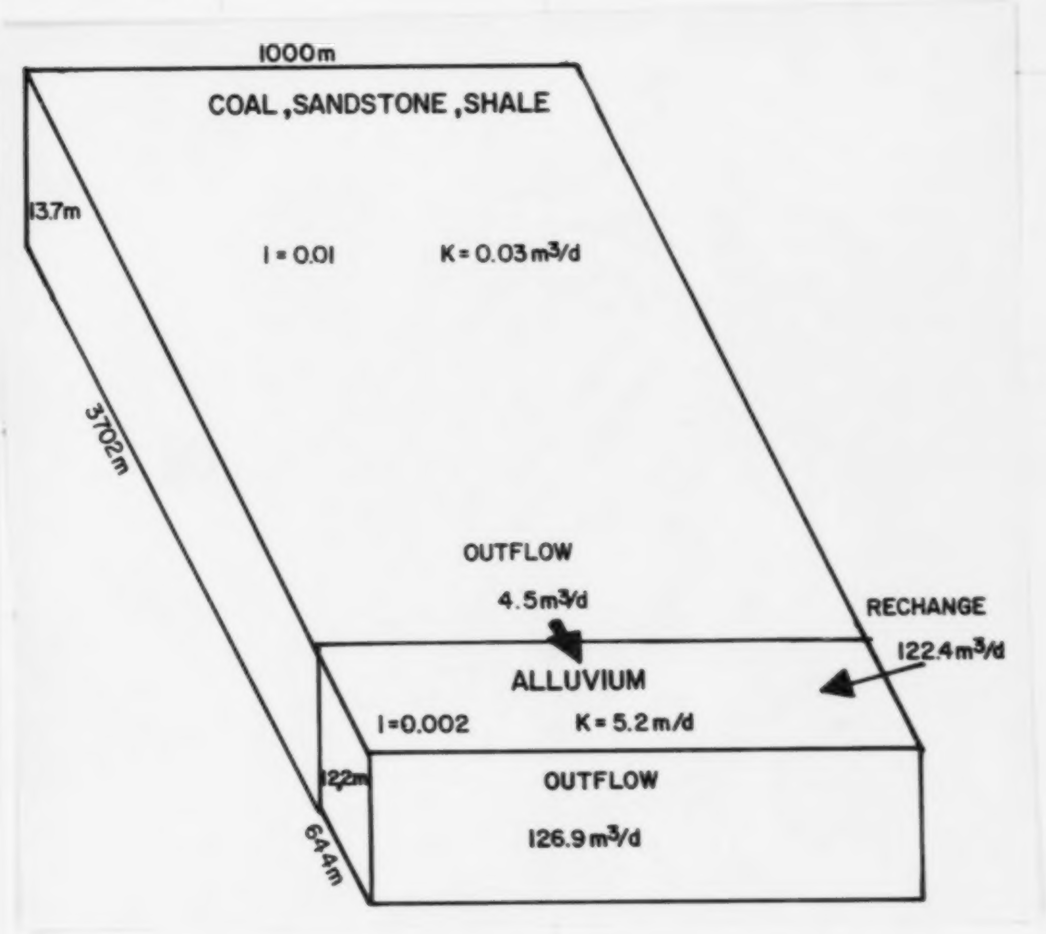
1000m
COAL, SANDSTONE, SHALE
13.7m
I = 0.01
K = 0.03 m3/d
3702m
OUTFLOW
4.5 m3/d
RECHANGE
122.4 m3/d
ALLUVIUM
I=0.002
K = 5.2 m/d
12.2m
OUTFLOW
126.9 m3/d
64.4m

Figure 6.19. Input-output model of the Indian Coulee Priority Study Area groundwater system.

The Indian Coulee Priority Study Area is typical of the area northwest of Rosebud Creek. It is believed that in most cases a near surface confined system is present and flow is from the northwest to the southeast with discharge into Rosebud Creek.

GROUNDWATER QUALITY

The quality of the groundwater in the Reservation flow systems is dependent on the quality and quantity of recharge waters, the type of aquifer minerals, hydraulic parameters controlling residence time, and the types of natural bacteria populations in the aquifers.

Precipitation in the form of rain and snow which is available for recharge contains only trace dissolved solids and has a pH of 5 to 6. No quality records were available for precipitation. Once these waters enter the soil and rock zones, the water begins to react chemically with the minerals. The longer the water is in contact with the earth materials and the greater the availability of soluble minerals in the strata, the more likely it is that the groundwater will reach a chemical equilibrium with the surrounding materials. Low hydraulic gradients and conductivities and long groundwater flow paths would promote quality equilibrium. Short flow paths, and large gradients and hydraulic conductivities would reduce the possibility for the water to approach equilibrium. Natural sulfur reducing bacteria associated with organics in some shale and in the organic coal of the region have been noted to have a significant influence on the ionic concentration in groundwater (BLM, 1977; Feder and Saindon, 1976). The life processes of these bacteria utilize sulfur derived from the earth material, reducing the sulfur concentration and producing a gas by-product.

Water Quality of Hydrostratigraphic Units

Review of 135 groundwater quality analyses of wells and 38 analyses of spring water quality indicated the principal constituents of the groundwater of the area were calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), bicarbonate (HCO_3^{-}), and sulfate (SO_4^{-}).

Generalization of the water quality of the Unconsolidated Unit, Anderson Unit, Knobloch Unit and Lower Tongue River Member Unit was difficult due to the variability of the earth material making up the units and the complex flow systems operating within the strata. However, a short discussion of the water quality by unit is presented to illustrate the quality of the groundwater in the area. Generally, less than 10 individual water analyses for wells finished in each unit were utilized. In all cases, wells had been sampled more than four times and average constituents concentrations were calculated for each sampling point. Single water analyses for other domestic wells and spring samples were also utilized to supplememnt NCRP data. Representative water quality analyses from wells finished in clinker, sandstone, coal, and unconsolidated material are presented in Appendix B. A specific discussion of the water quality of each priority site is presented after the general discussion to illustrate the quality variability and flow system relationships at specific sites.

Unconsolidated Hydrostratigraphic Unit

Analyses of water quality data indicated water from the unconsolidated material of the Rosebud Creek Valley and its major tributaries is generally a calcium magnesium-sulfate bicarbonate type, (TDS 428 mg/l to 2,200 mg/l). Water analyzed from the Tongue River Valley alluvium and its major tributaries is a sodium sulfate bicarbonate type (TDS 612 mg/l to 3,516 mg/l).

Tongue River Member Hydrostratigraphic Unit

Anderson Unit

Water quality data from the springs and wells within the Anderson Unit varied greatly. Evaluation of water chemistry data indicated water in the Anderson coal seam is generally a sodium bicarbonate type (TDS 1,000 to 3,000 mg/l). Water emanating from springs in the clinker portion of the aquifer is a calcium magnesium bicarbonate type (TDS 280 to 670 mg/l).

Knobloch Unit

Evaluation of water quality data from wells finished above and in the Knobloch coal shows water quality is variable. Water chemistry data from wells finished in sandstone and coal just west of Lame Deer were analyzed and indicated water was a sodium-sulfate type (TDS 1,000 to 3,000 mg/l) with sodium values over 1,000 mg/l in some cases. Sandstone deposits in the Lame Deer Creek Valley appeared to yield a calcium magnesium-bicarbonate type of water (TDS 200 to 1,000 mg/l). One sample from a domestic well finished in the Pawnee seam and an underlying sandstone showed water is a calcium sodium sulfate type (TDS 1,600 mg/l). Water from wells finished in the Knobloch coal was a sodium-bicarbonate type (TDS 766 mg/l).

Lower Tongue River Member Hydrogeologic Unit

Water quality data for the Lower Tongue River Member Unit were varied. Water from wells finished in sandstone in the Rosebud Creek Valley was a calcium magnesium-bicarbonate type (TDS 295 to 800 mg/l). Wells finished in the Rosebud, McKay, Flowers-Goodale, and local coal seams yield water that is a sodium sulfate type (TDS 250 to 1,500 mg/l). Analyses of water from a well finished in the Robinson coal seam showed it was a calcium magnesium-sulfate type (TDS 3,300 ppm).

Generally, water quality of surrounding area wells finished below the Lower Tongue River Member Unit for domestic, municipal, and stock use contained sodium bicarbonate water with TDS values of about 1,000 mg/l.

Water Quality and Flow System Relationships

It is generally held that groundwater associated with recharge areas in the Fort Union Formation is principally a calcium, magnesium, bicarbonate, sulfate type (Feder and Saindon, 1976). It has been reported that, as water moves through an oxidizing environment associated with a recharge area, the TDS and the percent of magnesium and sulfate increase (BLM, 1977). As the water percolates through sodic shales and siltstones in reducing environments, magnesium-calcium ions exchange with sodium ions. Sulfur bacteria begin reducing sulfate in the presence of coal and organic material found in some shale:

$SO_4^{-2} + CH_4$ --- Reducing Environment Bacteria ---> $H_2S + HCO_3^{-1} + OH^{-1}$

(BLM, 1977)

Reduction of sulfate will also occur in the presence of ferrous iron:

$2\ Fe^{+2} + 4SO_4^{-2} + 2H_2O + 7C$ -----> $2FeS_2 + 4HCO_3^{-1} + 3\ CO_2$

(BLM, 1977)

The result of these reactions is a decrease in calcium, magnesium and sulfate and an increase of sodium and bicarbonate down gradient from the recharge area. These reactions also result in a slight decrease in TDS, the precipitation of trace metals, and a rise in pH values. As the water continues along the flow path, TDS will increase until the groundwater has reached equilibrium with the mineral chemistry of the aquifer, additional recharge is received, or until the water is discharged.

The above factors result in groundwater of a varied quality depending on the material it flows through, the length of the time that the water is in the system and the biological reactions which have taken place.

Priority Area Water Quality

Water quality data for each priority site were evaluated by utilizing the water quality - flow system relationships described previously. The presence of high concentrations of calcium, magnesium and sulfate ions relative to sodium and bicarbonate ions was considered representative of groundwater receiving recharge. The presence of large concentrations of sodium and bicarbonate ions relative to the other ions was bicarbonate ions was considered representative of groundwater down gradient from the recharge area. Water composed of principally sodium and sulfate ions was considered representative of two possible situations: 1) Water down gradient from the recharge area not receiving recharge, that has undergone ion exchange and reacts with aquifer material high in soluble sulfate. Gysiferous shales could supply a source of calcium and sulfate ions to the groundwater. 2) Water in an unconfined system, which has undergone ion exchange but not sulfate reduction because of the absence of reducing conditions.

Logging Creek Priority Study Area

The water quality in the wells in the Logging Creek Study Area are depicted graphically in Figure 6.20. Wells NCRP 21, 27, 29A and 8A are all finished in the Knobloch coal seam. Sodium is the dominant cation in all of the wells. This suggests that calcium magnesium exchange has taken place. The water quality data from the wells finished in the Knobloch coal suggest that recharge occurs to the Knobloch coal in the central plateau region and also near the Tongue River where the overburden thins. Water in wells

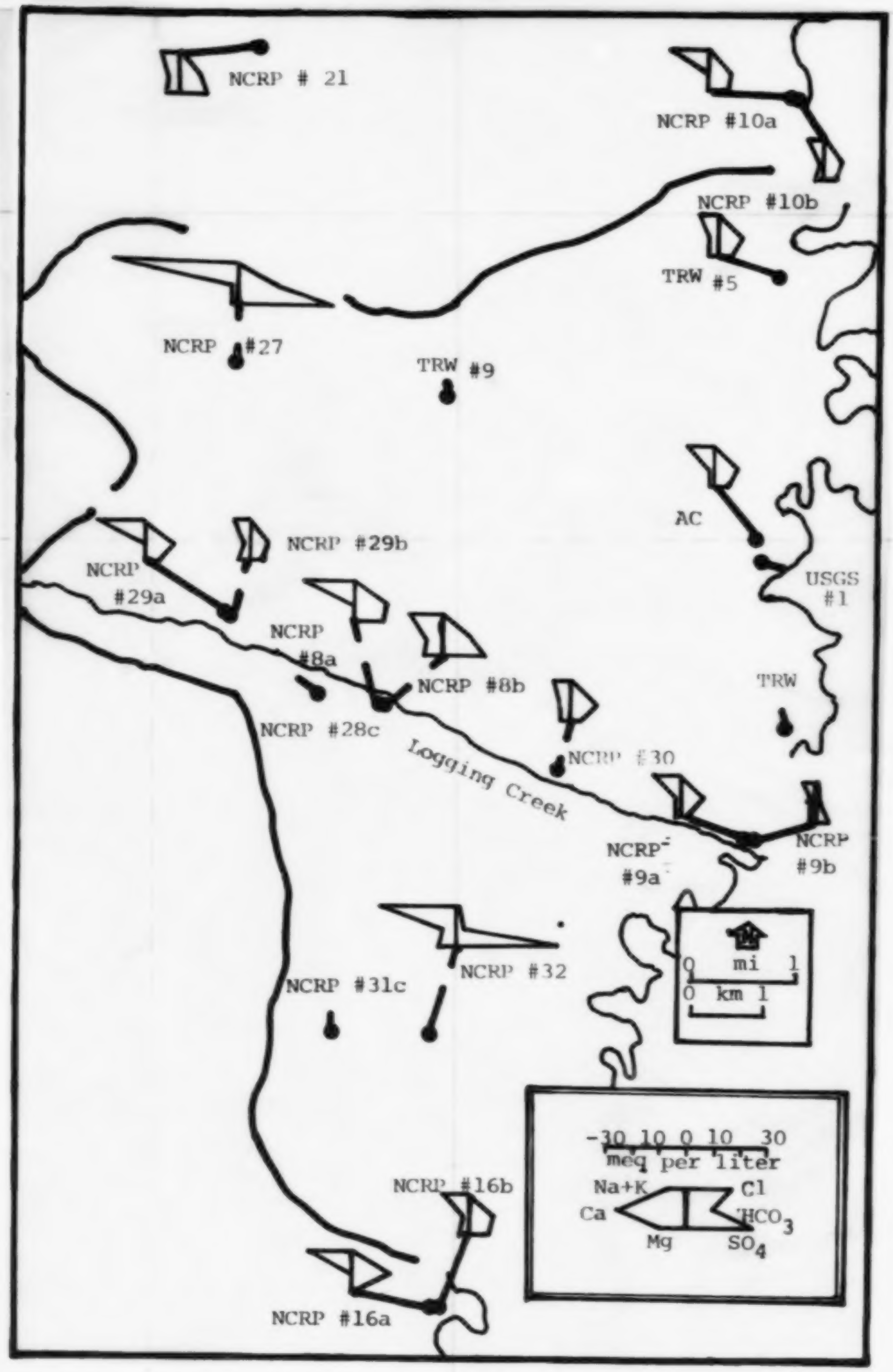
NCRP # 21
NCRP #10a
NCRP #10b
TRW #5
NCRP #27
TRW #9
AC
USGS #1
NCRP #29b
NCRP #29a
NCRP #8a
NCRP #8b
NCRP #28c
TRW
NCRP #30
Logging Creek
NCRP #9a
NCRP #9b
0 mi 1
0 km 1
NCRP #32
NCRP #31c
-30 10 0 10 30
meq per liter
Na+K
Cl
Ca
HCO3
Mg
SO4
NCRP #16b
NCRP #16a

Figure 6.20. Water quality data for Logging Creek Priority Study Area.

finished in the sandstone below the coal and alluvium, NCRP 16A and 10A and TRW 5, is a sodium bicarbonate type. This suggests that recharge is not occuring to this unit in the valley area. Water in the Tongue River alluvium, from wells NCRP 16B and 10B and AC1, are a composite of calcium magnesium sulfate water and sodium bicarbonate water. This suggests that direct recharge to the alluvium and discharge to the alluvium from deeper flow systems mix to give the characteristic water type found in the alluvium.

The groundwater quality data support the identified local and regional flow systems in the Logging Creek Area. A confined Knobloch coal flow system is only receiving recharge in this area in regions of thin overburden near the coal clinker boundary. Recharge also occurs directly to the clinker and alluvium. The data indicate that the alluvium is receiving recharge from clinker outflow, direct recharge, and upward seepage from deeper systems.

Buffalo Jump Priority Study Area

Water quality data from wells located in the Buffalo Jump Priority Study Area are presented in Figure 6.21. Wells NCRP 22, 4, and 26 are finished in the Anderson coal. Water from NCRP 4, in the center of the groundwater mound in the coal, contains high calcium, bicarbonate, and sulfate concentrations. This indicates that reducing reactions take place within 3.2 km (2 mi) of the central recharge area. Water from NCRP 24, finished in partially burned coal and clinker, and springs emanating from the Anderson clinker, are low in TDS. The water is a calcium-sodium-bicarbonate type. This indicates that the clinker is recharged in sufficient quantity to dilute the higher TDS waters from the coal that also recharges the clinker. The water quality in NCRP 23A and 23B, which are finished in units below the Anderson coal, indicate that water from the Anderson clinker is recharging the lower sandstones and local coal units.

The groundwater quality data support the identified coal flow system in the Buffalo Jump Area. The data indicate that recharge occurs in the center of the area, and that the water moves radially from the central region. Water from the Anderson coal flow system enters the clinker zone and is diluted by large quantities of recharge, and discharges as high quality spring water.

Indian Coulee Priority Study Area

Water quality data from wells located in the Indian Coulee Priority Study Area are presented in Figure 6.22. Wells NCRP 40A, and 36A are finished in the McKay coal seam. Wells NCRP 39B and 35B are finished in alluvial material in the coulees, and NCRP 39A is finished in a sandstone. Well NCRP 35A is completed in the Robinson Coal. High sodium, calcium, magnesium, and sulfate concentrations, in all wells except NCRP 40A and 39B, suggests that sodic shales are present in the aquifer, and ion exchange has occurred. However, sulfate has not been reduced. High concentrations of calcium and magnesium in wells NCRP 39B and 40A suggest that these wells are located in recharge areas.

The groundwater quality data support the identified local flow systems

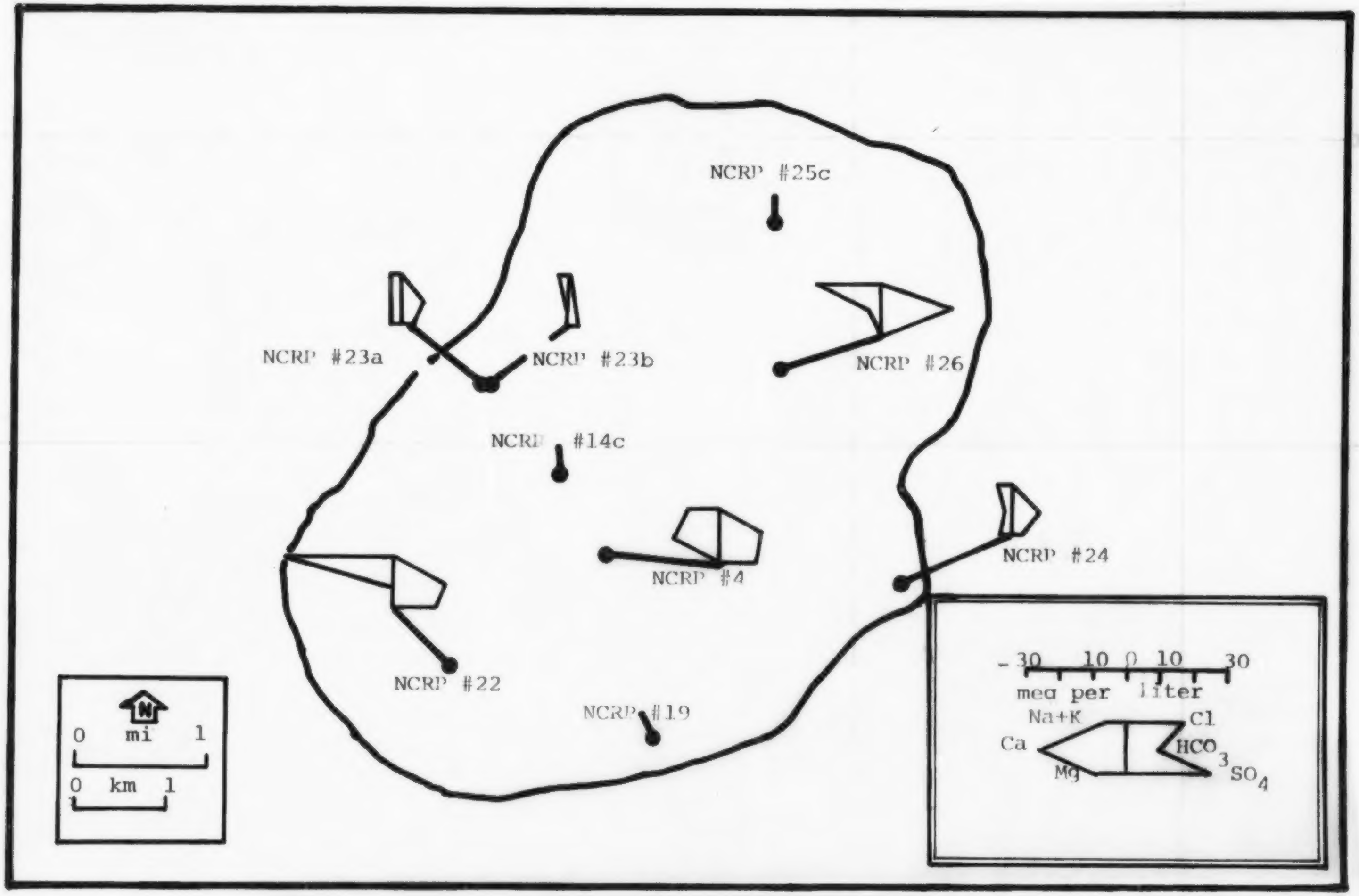
NCRP #25c
NCRP #23a
NCRP #23b
NCRP #26
NCRP #14c
NCRP #4
NCRP #24
NCRP #22
NCRP #19
0 mi 1
0 km 1
- 30 10 0 10 30
meq per liter
Na+K
Ca
Mg
Cl
HCO3
SO4

Figure 6.21. Water quality data for the Buffalo Jump Priority Study Area.

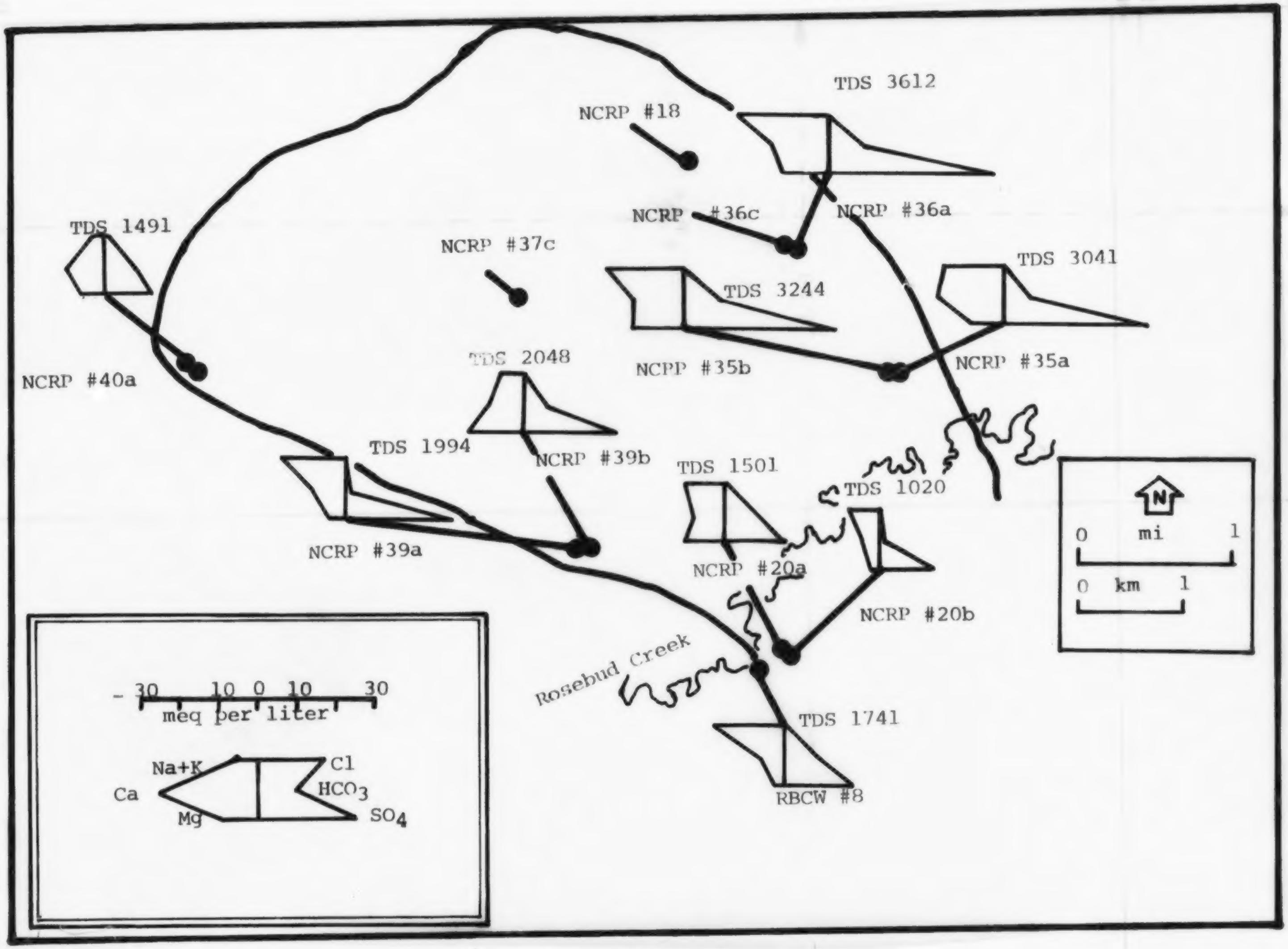
TDS 3612
NCRP #18
NCRP #36c
NCRP #36a
TDS 1491
NCRP #37c
TDS 3041
TDS 3244
TDS 2048
NCRP #40a
NCPP #35b
NCRP #35a
TDS 1994
NCRP #39b
TDS 1501
TDS 1020
NCRP #39a
NCRP #20a
NCRP #20b
N
0 mi 1
0 km 1
Rosebud Creek
TDS 1741
RBCW #8
- 30 10 0 10 30
meq per liter
Na+K
Cl
Ca
HCO3
Mg
SO4

Figure 6.22. Water quality data for Indian Coulee Priority Study Area.

in the Indian Coulee Area. Analyses of water quality data indicate that a near surface groundwater system exists in which ion exchange is occurring. It is likely that sulfate reduction is not occurring.

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CHAPTER 7

SURFACE WATER

INTRODUCTION

The Northern Cheyenne Reservation lies within the Yellowstone River sub-basin of the Missouri River. Surface water runoff is directed to two tributaries of the Yellowstone River: the Tongue River, and Rosebud Creek. The Tongue River is the larger stream with its headwaters in the Bighorn Mountains of Wyoming, while Rosebud Creek is a prairie stream in its entirety.

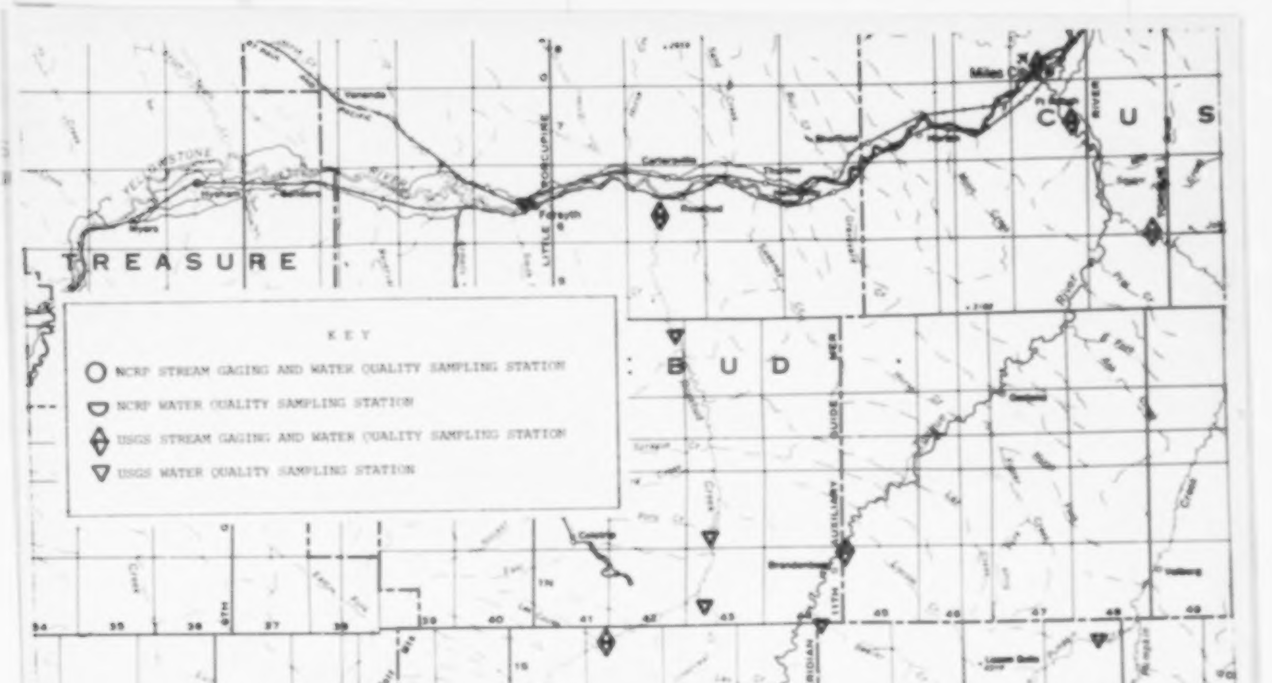
This chapter characterizes the surface water hydrology and water quality of the Tongue River and Rosebud Creek in Montana, specifically those reaches along the Northern Cheyenne Reservation. This is discussed to give as complete a picture as possible of the natural surface water systems and their relation to the basic geologic setting, groundwater system, meteorological data, and land and water uses in the basins.

The chapter is divided into two principal parts: the first deals with streamflow characteristics and discharge data; the second addresses water quality parameters. Both sections discuss regional or basin-wide characteristics first, followed by a more specific presentation focusing on the Northern Cheyenne Reservation. Both sections conclude with an analysis and presentation of the parameters used for modeling the potential impact of coal surface mining on the Northern Cheyenne Reservation.

The principal hydrologic parameters discussed in this chapter are the flow of the Tongue River and Rosebud Creek and their tributaries during the 1976 and 1977 water years, and results of groundwater seepage measurements.

A description of the chemical characteristics of the surface water includes: 1) total dissolved solids (TDS) variations with streamflow within the Tongue River and Rosebud Creek basins; 2) water type and the ionic constituents comprising TDS at each sampling station during different seasons and discharge rates; 3) the frequency distributions of TDS concentrations; 4) the variation of discharge and TDS at each gaging station; and 5) the calculation of time-averaged and discharge-averaged TDS values for each station.

It was concluded that present-day streamflow and water quality characteristics of the Tongue River along the Northern Cheyenne Reservation are primarily determined by upstream basin features such as mountain snowmelt, irrigation, and the Tongue River Reservoir. Groundwater discharge to the Tongue River, below the Tongue River Dam, averaged approximately 16 percent of the total streamflow at the northern Reservation boundary during the



TREASURE
ROSEBUD
CUSTER
KEY
○ NCRP STREAM GAGING AND WATER QUALITY SAMPLING STATION
NCRP WATER QUALITY SAMPLING STATION
USGS STREAM GAGING AND WATER QUALITY SAMPLING STATION
▽ USGS WATER QUALITY SAMPLING STATION
YELLOWSTONE RIVER
LITTLE PORCUPINE
Forsyth
Miles City
NORTHERN CHEYENNE INDIAN RESERVATION
RBC #1
LDC #1
LDC #2
MC #1
TR #1
LC #1
CC #1
TR #2
RBC #2
BIG HORN
POWDER
N
km

Figure 7.1. Locations of NCRP and USGS stream gaging and water quality sampling stations on Tongue River and Rosebud Creek.

baseflow periods measured. The mean discharge of Rosebud Creek approximately doubles within the Reservation boundaries. Groundwater discharge to Rosebud Creek comprised about 23 percent of the total discharge at the northern Reservation boundary during the baseflow periods measured. The highest seepage rates occurred upstream from Busby, Montana. Clinker deposits were found to be the principal aquifer materials contributing baseflow in the upper reach. The tributaries of Muddy Creek and Lame Deer Creek convey significant amounts of baseflow from bedrock and alluvial aquifers to Rosebud Creek.

Total dissolved solids averaged 503 mg/l in the Tongue River at the NCRP sampling station below Ashland: an eight percent increase over the upstream station, near Birney. The TDS cycled between highs during baseflow periods, to lows following release of snowmelt runoff water from Tongue River Reservoir. Groundwater discharge increased surface water TDS in the downstream direction during baseflow periods.

TDS averaged 758 mg/l in Rosebud Creek at the NCRP sampling station north of Lame Deer: a 37 percent increase over the upstream station near Kirby. The increase resulted from elevated TDS levels present in additional groundwater and surface water contributions.

PREVIOUS REPORTS

Almost all previous investigations examining the surface water resources of the Northern Cheyenne Reservation are reconnaissance reports. The Northern Cheyenne 208 Water Quality Management Plan (1977) reported surface water quality and discharge data, and initial hydrologic system analyses. The work was authored by the Northern Cheyenne Research Project with some of the results included in this report.

The U.S. Bureau of Indian Affairs (BIA) contracted with HKM and Associates consulting firm (1972, 1973, 1975) to prepare a three phase water resources report summarizing existing water resource data for the Northern Cheyenne Reservation. The report primarily addresses water supply and storage opportunities on the Reservation. General watershed characteristics were discussed. Basin characteristics and flow estimates for Tongue River, Rosebud Creek and tributaries were developed; however, the hydrologic data base was limited at that time.

In 1973, the U.S. Geological Survey (USGS) completed a water supply atlas of southeastern Montana, including the Northern Cheyenne Reservation (Hopkins, 1973). Ten miscellaneous discharge measurements were made on Rosebud Creek during 1968 and 1969 near the northern Reservation boundary. No measurements were made of the Tongue River, and no water quality data were collected.

The Montana Department of Health and Environmental Sciences, Water Quality Bureau completed a Water Quality Inventory and Management Plan for the Middle Yellowstone River Basin (Karp and Botz, 1975), including Tongue River and Rosebud Creek. Several synoptic water quality sampling and flow measurement runs were conducted in 1973 and 1974 on the Tongue River from the Tongue

River Dam to Miles City, and on Rosebud Creek from Kirby to the mouth. The Water Quality Bureau presented a brief analysis of the field data collected.

Other investigations of water resources that have been conducted in southeastern Montana assisted in the regional hydrologic analyses contained in this report. Most notably, a report by the USGS, Water Quality of Selected Streams in the Coal Area of Southeastern Montana (Knapton and McKinley, 1977) and the Water Quality Management Plan and ancillary reports by the Yellowstone Tongue Area-Wide Planning Organization (YTAPO, 1978) provided the most assistance.

HYDROLOGY METHODS

Very little hydrologic data existed for the Northern Cheyenne Reservation prior to this investigation. Existing stream gaging stations were generally well-removed from the Reservation boundaries, and data were insufficient for the assessment of mining impacts on the Reservation.

For these reasons, the NCRP initiated a surface water monitoring program in 1975. The NCRP and permanent USGS surface water gaging and water quality sampling stations in the basins are shown in Figure 7.1. The basic rationale for the monitoring program was to establish streamflow characteristics and discharge values for the Tongue River and Rosebud Creek at the reservation boundaries, and for their principal tributaries. Water quality data were collected at stream gaging stations so that flow-quality relationships could be developed. Groundwater monitoring wells were also located near gaging stations so that water levels and river stage could be readily compared. The attempt was made to gather as much concurrent data as possible on the hydrologic cycle to provide an understanding of the overall natural system.

STREAMFLOW MEASUREMENT STRUCTURES

The gaging station network established by the NCRP on the Reservation included three servo-manometer bubble gages and five stilling wells with float-type systems. Control structures on smaller streams included three trapezoidal weirs and one Parshall flume. Station equipment is summarized in Table 7.1.

The weirs were designed by HKM Associates, an engineering consulting firm from Billings, Montana. All gaging stations and weir installations were supervised by Morningstar Enterprises of Lame Deer, Montana. The design of gaging shelters and instrument set-up generally followed the recommendations of the USGS (Buchanan and Somers, 1968). Sites for location of gaging stations were recommended by the USGS or HKM Associates in consultation with the NCRP. Following installation and initial operation of the gaging stations, an HKM engineer inspected each installation in April 1977.

TABLE 7.1. STREAMFLOW GAGING STRUCTURES ON THE NORTHERN CHEYENNE RESERVATION

STATION	STRUCTURE
Tongue River #2	Gaging shelter and stilling well, Stevens A-71 recorder with float, outside staff gage, cableway.
Tongue River #1	Gaging house, servo-manometer bubble-gage and recorder, outside staff gage, cableway.
Rosebud Creek #2	Gaging house, servo-manometer bubble-gage and recorder, outside staff gage, bridge.
Rosebud Creek #1	Same as Rosebud Creek #2.
Cook Creek #1	Seven foot Cipolletti weir, gaging shelter with stilling well, Stevens A-71 recorder with float, outside gage.
Logging Creek #1	Three foot parshall flume, gaging shelter with stilling wells, Stevens A-71 recorder with float, outside staff gage.
Lame Deer Creek #1	Same as Cook Creek #1
Muddy Creek #1	Cement bag trapezoidal weir, gaging shelter with stilling well, Stevens A-71 recorder with float, outside staff gage.

GAGING STATION OPERATION

NCRP gaging stations were operated according to manufacturer's suggestions and recommendations of the USGS (Buchanan and Somers, 1968). A record sheet was maintained in each gaging house to note the date and time of visit, inside and outside stage measurements, air temperature, operation of equipment and name of the observer. A separate field record book was maintained to record the same information plus water quality data and other field observations.

Most gaging stations were visited at least once per month to wind clocks, change charts, and flush intake pipes.

Gaging stations with stilling wells and floats were winterized by suspending a piece of PVC pipe within the stilling well and adding light-weight oil and fuel oil to the pipe to prevent freeze-up under the float. This procedure appeared to work during the winter of 1976-77, but did not work as well during 1977-78, when temperatures near -40°C (-40°F) were recorded. Discharge measurements were made under ice cover so that adjustments to the winter stage-discharge relations could be made. In general, however, the accuracy of winter stage records is poorer than for other seasons. Gas bubble gage stations functioned well during winter months and only normal maintenance was required. The record flood during May, 1978 caused some damage to several outside staff gages and the orifice pier at TR#1.

Beaver activity caused problems at several stations on small tributaries. In particular, the Muddy Creek gaging station was flooded out by a series of beaver dams downstream.

STREAMFLOW MEASUREMENT TECHNIQUES

The NCRP stream gaging program included monthly current meter measurements at 13 sites (Figure 7.2). Streamflow measurements were usually made beneath ice cover from December through March. All current meter measurements were made utilizing techniques recommended by the USGS (Carter and Davidson, 1968 and Buchanan and Somers, 1969). Normally, 20 or more sections were measured across the stream channel and most discharge values were accurate to within 5 percent. Exceptions occurred on very small streams (less than one meter wide) or during winter if ice conditions limited access or the number of holes bored. At times, float tests or bucket gaging methods were used to obtain discharge values on small tributaries. River stage measurements were taken concurrently with discharge measurements, and stage-discharge relationships were developed. Rating curves were developed from which spot stage measurements or continuous stage records could be transformed into discharge values.

At NCRP Station TR#2, a State of Montana stage-discharge relationship developed from 1968-73 irrigation season measurements was used to assist in analyzing NCRP data.

SEEPAGE RUNS

Seepage runs, a series of discharge measurements along a stream reach made in one or two days during baseflow periods, were used to evaluate groundwater discharge rates to Rosebud Creek and Tongue River. Discharge measurements were made with current meters, or in two instances, taken from stage-discharge relations. Seepage run techniques and data analysis followed that outlined by the USGS (Riggs, 1972). On several occasions, the NCRP cooperated with the USGS and the State of Montana agencies in seepage runs

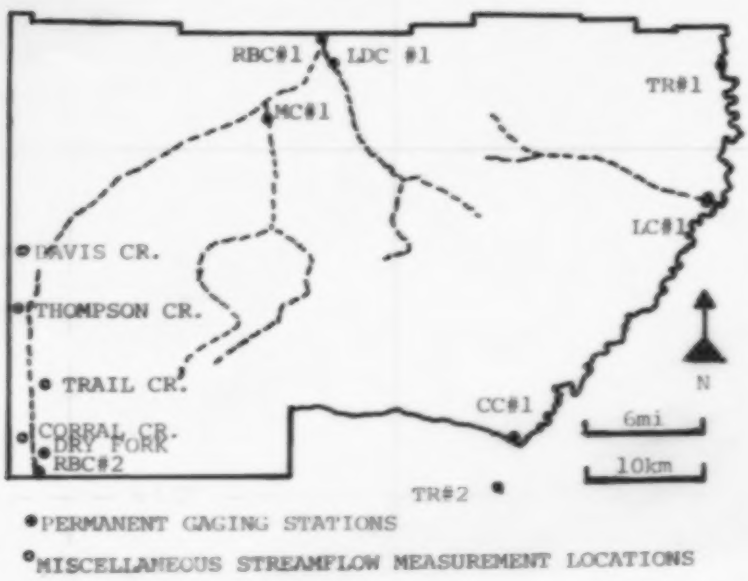


Figure 7.2. Location of streamflow measurement sites.

on the Tongue River and Rosebud Creek. The NCRP performed the discharge measurements in the reaches on or along the Reservation. Discharge measurement notes and other raw data were obtained from the USGS to aid in the evaluation of groundwater seepage throughout the entire length of both river channels in Montana.

Typical current meter measurements inherently contain an error of ±5 percent. This error added to the normal variability of streamflow indicates detailed estimates of groundwater discharge are difficult to make. For these reasons, groundwater inflow estimates were based primarily on measurements taken on the same day by the same agency.

The inconsistency of the discharge measurements and resulting groundwater inflow estimates made correlation of these data difficult. For example, in the 1975 seepage run, one pair of measurements at the Tongue River Dam and Birney Day School resulted in an inflow rate of +0.123 m^3/sec/r km or +0.67 ft^3/sec/r mi. Six days later, a measurement in the same reach by a different agency resulted in a net discharge loss at the rate of -0.012 m^3/sec/r km (-0.67 ft^3/sec/r mi).

These inconsistencies are the result of a combination of inherent discharge measurement error and natural or man-caused streamflow changes. The groundwater inflow component of the measurements can easily be obscured by these errors and by minor streamflow fluctuations as well. However, averaging techniques and general inspection of the raw data indicated regional trends that are discussed in this chapter.

Both discharge-weighted and unweighted groundwater seepage rates were calculated because it could not be determined which was more representative of actual conditions. Although inflow rates calculated from two streamflow measurements relatively close together can be in error due to the inherent ±5 percent current meter measurement error, measurements taken over a long distance sometimes include effects of diversions, evaporative losses, or changes in dam releases. A practical method for spacing current meter measurements in seepage runs is to allow enough distance so that the net amount of groundwater discharge expected in that reach exceeds at least 5 percent of the total stream discharge.

WATER QUALITY METHODS

Surface water quality can be characterized by a variety of physical, chemical, and biological measurements. Physical measurements taken during this two year study included water temperature during station visits and suspended sediment on a intermittent basis. Chemical measurements were made of 12 common ions, TDS, hardness, alkalinity, electrical conductivity, pH, and a total of 16 trace metals.

Water samples usually were collected once per month at each surface water gaging station. Samples were filtered in the field through a 0.45 micron filter into plastic 1.9 liter (2 quart) bottles. A portion of each sample was placed in a second bottle and preserved with concentrated nitric acid for metals analyses. All samples were kept sheltered in the field and, if necessary, stored temporarily in a refrigerator. Samples were normally mailed to Billings on the day of collection and analyzed within 24 hours of collection. All laboratory analyses were performed by Energy and Environmental Resources Consultants, Inc., Billings, Montana. The laboratory received certification by the EPA prior to initiation of this study. Environmental Protection Agency test samples and NCRP split samples were acceptably analyzed by the lab midway through the study.

SURFACE WATER HYDROLOGY

A map outlining the location of watersheds under investigation in this study is presented in Figure 7.3. A summary of the principal watershed characteristics of drainages on the Northern Cheyenne Reservation is presented in Table 7.2. Scenes of Tongue River and Rosebud Creek are shown in Plate 7.1.

The surface water hydrology of the Tongue River is discussed first, followed by that of Rosebud Creek. Within both of these subsections, regional basin characteristics, stream discharge data, and groundwater discharge rates are presented.

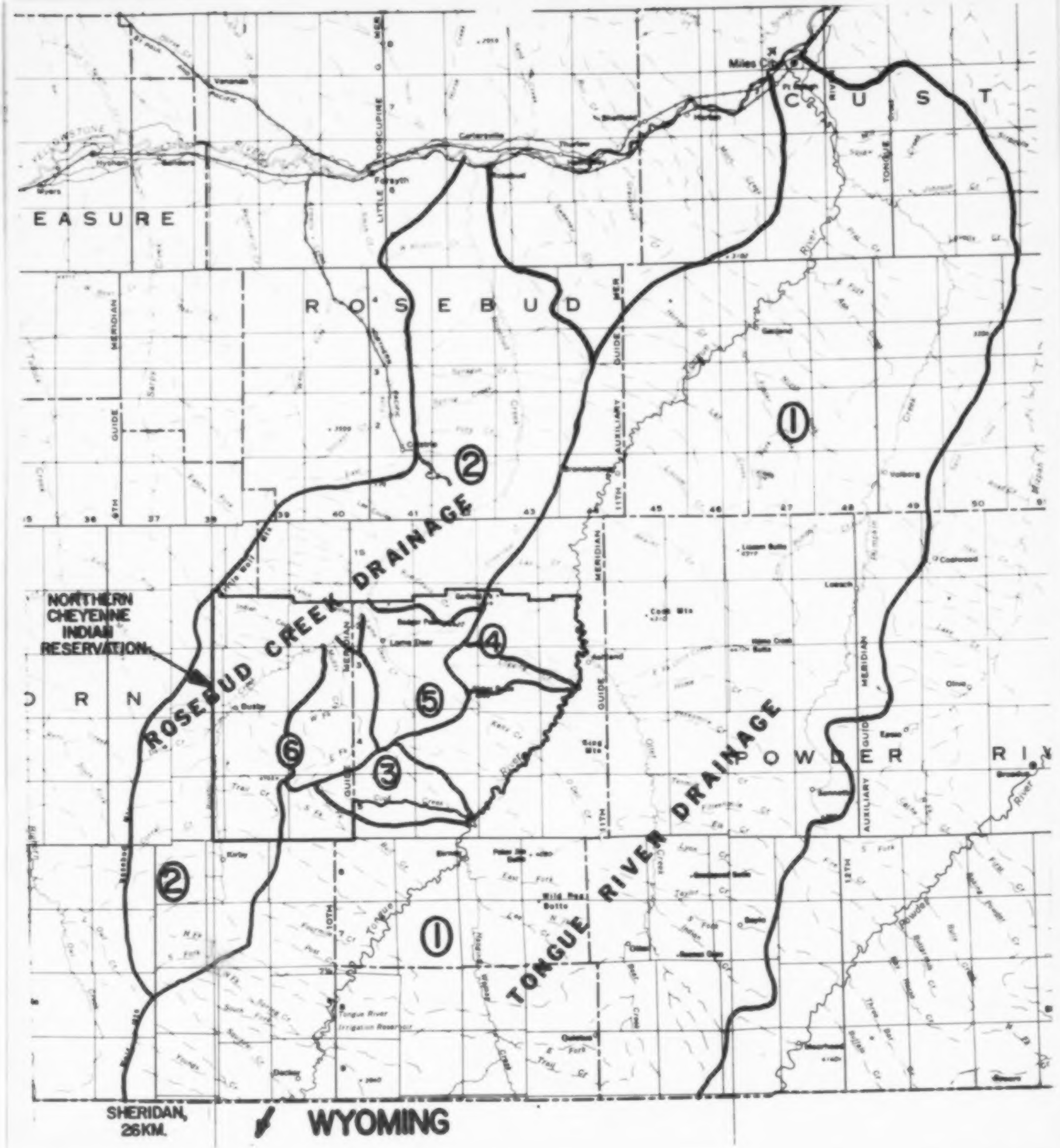

Miles City
C U S T
EASURE
Forsyth
R O S E B U D
①
②
ROSEBUD CREEK DRAINAGE
NORTHERN CHEYENNE INDIAN RESERVATION
④
⑤
⑥
③
R N
TONGUE RIVER DRAINAGE
P O W D E R
R I
②
①
SHERIDAN, 26KM.
WYOMING

Figure 7.3. Locations of drainage basins under study (basin numbers refer to TABLE 7.2).

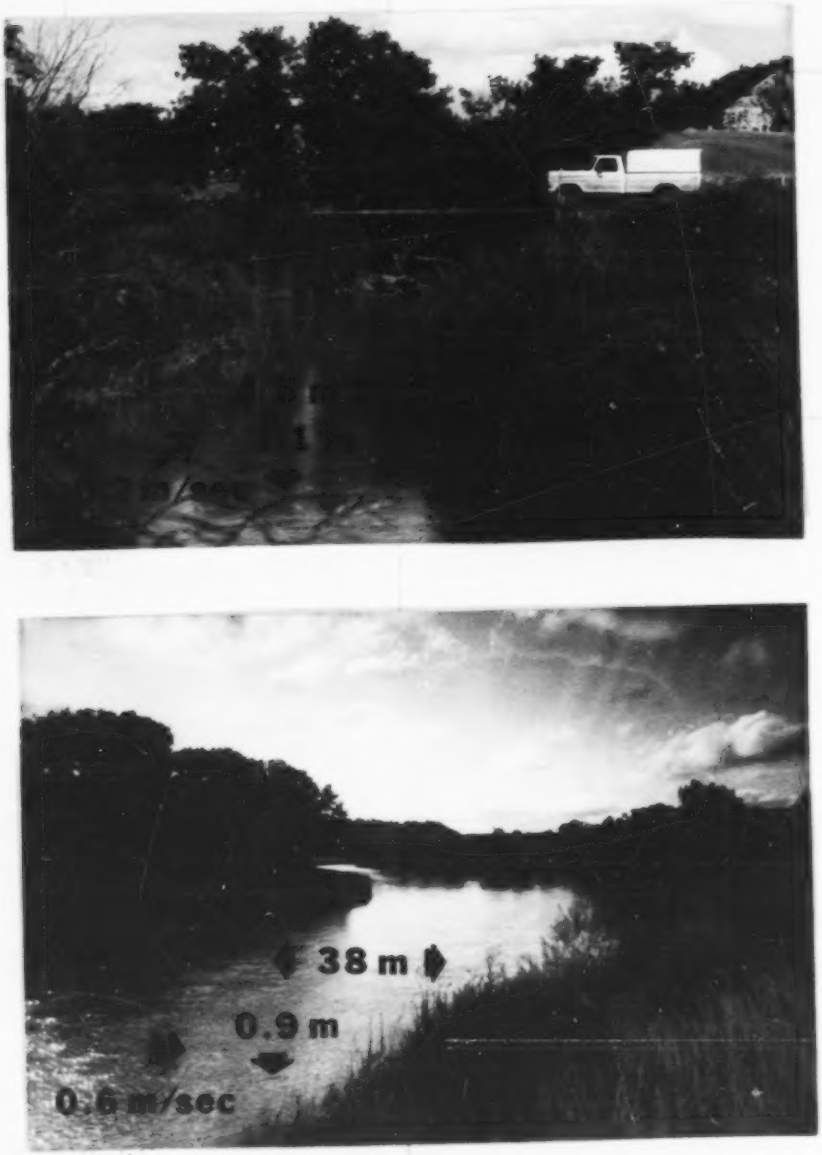


Plate 7.1 Scences of Rosebud Creek near Busby, Montana (a) and the Tongue River near Ashland, Montana (b), with typical velocity, depth and width measurements given.

TABLE 7.2. SUMMARY OF WATERSHED CHARACTERISTICS, NORTHERN CHEYENNE RESERVATION DATA

Map No.	Drainage	Watershed Area Km^2 (mi^2)	Headwaters Elevation m (ft)	Mean Annual Precip. cm (in)	Irrigated Area Km^2 (acres)	Mean Annual Discharge m^3/sec (ft^3/sec)	Dominant Water Source of Stream	Mean Gr.-water discharge rate m^3/sec/r. km (ft^3/sec/r.mi)
1	Tongue River at Miles City	10.107 (3,902)	3900 m (12,000 ft)	30-36 (12-14)	364 (90,000)	12.49 (441)	Surface Water from Bighorn Mountains	0.01 (0.55)
	Tongue River at Stateline	3825 (1,477)		30-63 (12-25)	260 (64,300)	14.47 (511)		
2	Rosebud Creek at Mouth	3,372 (1,302)	1640 (5,000)	30-36 (12-14)	8.09 (2,000)	0.98 (34.6)	Surface Tributaries and ground water	0.001 (0.07)
	Rosebud Creek @ no. Res. Bdry.	1,653 (638)		36-41 (14-16)	122 (300)	0.96 (33,9)		
3	Cook Creek	167 (64.3)	1370 (4,500)	30-41 (12-16)	0.20 (50)	0.03 (1.26)	Groundwater	
4	Logging Creek	98.4 (38)	1280 (4,200)	30-41 (12-16)	0	0.021 (0.73)	Surface run-off and ground water	
5	Muddy Creek	266 (103)	1280-1370 (4200-4500)	36-41 (14-16)	0	0.087 (3.07)	Groundwater	
6	Lame Deer Cr.	212 (81.9)	1280 (4,200)	36-41 (14-16)	0.24 (60)	0.061 (2.17)	Groundwater	

THE TONGUE RIVER

Basin Features and Characteristics

The Tongue River has its headwaters in the Bighorn Mountains of Wyoming, where elevations range to over 3,900 m (13,000 ft). Annual precipitation averages over 63 cm (25 in), occurring primarily as winter snowfall and spring to early summer rainfall. Major snowmelt occurs during May and June. The Northern Cheyenne Reservation lies approximately 100 km (60 mi) northeast of the base of the Bighorn Mountains. The Tongue River forms the entire eastern boundary of the Reservation for 76 river kilometers (47 river miles). Elevations along this portion of the valley range from 945 m (3,100 ft) near Birney Village to 872 m (2,860 ft) north of Ashland, Montana. Dissected plateaus and benches rise from either side of the valley to elevations of 1,460 m (4,800 ft). Annual precipitation ranges from 30 to 43 cm (12 to 17 in) depending on elevation. Seasonal and year to year variability is high. The Tongue River Reservoir has a storage capacity of about 84,000,000 m^3 or 69,000 ac ft (acre feet), and is located 60 river kilometers (37 river miles) upstream from the southern Reservation boundary. The Tongue River Dam has been in operation since 1940, and regulates the river for downstream irrigation purposes. It has an annual yield of 49,000,000 m^3 (40,000 ac ft) currently obligated to existing users.

The average annual historical discharge of the Tongue River at its mouth near Miles City, Montana is 12.5 m^3/sec (cubic meters per second), or 441 ft^3/sec (cubic feet per second), (USGS, 1977). The drainage area is 13,932 km^2 (square kilometers) or 5,379 mi^2 (square miles). The mean annual discharge upstream at the Reservation and Tongue River Dam is slightly higher indicating that downstream depletions during the growing season have historically diminished streamflow.

Local residents recall that the Tongue River had no apparent flow on several occasions prior to the construction of the Tongue River Dam. USGS records (1977) indicate that the discharge of Tongue River was near zero in 1940, during parts of July, August, and September. The largest flood of record on the Tongue River occurred in May 1978, following 12 to 18 cm (5 to 7 in) of rain in a two-day period.

The Tongue River Valley has a fairly continuous riparian stand of cottonwood, ash, and other vegetation that transpire water during the growing season. Deep-rooted species, such as alfalfa and sagebrush in bottomland fields are sub-irrigated during most growing seasons. Two large municipalities, Sheridan, Wyoming, and Miles City, Montana, the smaller community of Ashland, Montana, and numerous individual house and stock wells derive water supplies from the Tongue River alluvium. The Tongue River Valley is good grazing land, and livestock use both the river and the numerous small reservoirs in the basin.

Gaging Stations on the Tongue River

There are currently five USGS and two NCRP stream gaging stations on the

Tongue River in Montana (Figure 7.1). Station numbers and periods of record are given in Table 7.3.

TABLE 7.3. STREAM GAGING STATIONS ON THE TONGUE RIVER IN MONTANA

STATION		STRUCTURE
Tongue River at Miles City, MT	06308500	April, 1938 to April, 1942 April, 1946 to current year
Tongue River below Brandenberg Bridge, Near Ashland, Mt	06307830	October, 1973 to current year
NCRP Tongue River #1 Near Ashland, MT		July, 1977 to current year
NCRP Tongue River #2 Near Birney, MT		April, 1976 to current year
Tongue River at Tongue River Dam, Near Decker MT	06307500	May, 1939 to current year
Tongue River at State Line, Near Decker, MT	06306300	August, 1960 to current year
Tongue River at Dayton, Wyo.	06298000	October, 1919 to current year

A short period of record, 1967 to 1973, is available for the Tongue River below Hanging Woman Creek, near Birney, Montana, No. 24C02000, but only for the months of April or May through November. This station was installed and operated by the Montana Department of Natural Resources and Conservation (DNRC), and is located about 3 river kilometers south of the Reservation line. The station was reactivated by the NCRP as Tongue River #2 (TR 2) in October 1975. Continuous water stage records are available since April 1976.

Another short record station installed and operated by the DNRC is located on the Tongue River below the Brandenberg Bridge, about 40 river kilometers (25 river miles) north of the northern Reservation boundary. Seasonal records for 1966 through 1973 are available. In October 1973, the USGS commenced operation of this station (No. 06307830), and has maintained year-round records since that time.

The Source of Tongue River Water

The majority of surface runoff originates in Wyoming, principally from Bighorn Mountain snowmelt. One estimate indicated that about 90 percent of the inflow to the Tongue River Reservoir is from mountain runoff (USGS and State of Montana, 1977). A graph of mean discharge versus percent of basin area (Figure 7.4) demonstrates the significance of mountain runoff in supplying most of the total discharge of the Tongue River.

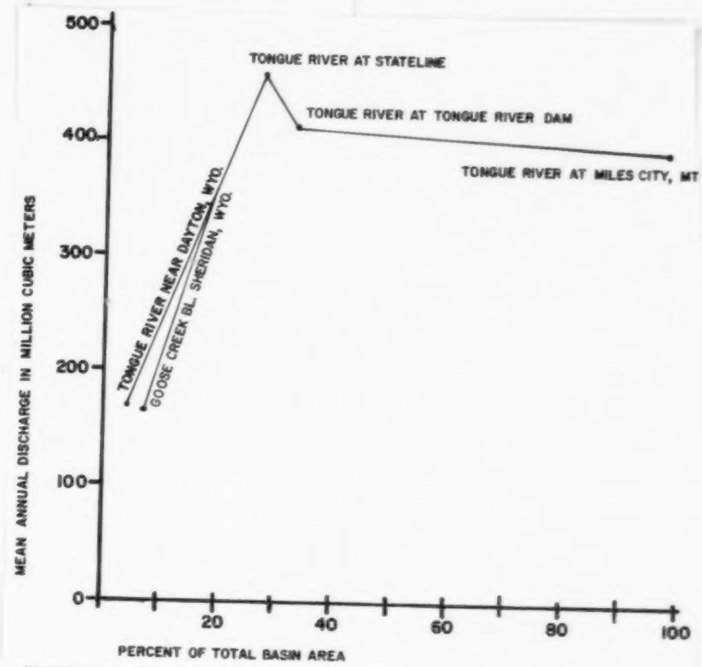


Figure 7.4. The variation of mean annual discharge with the percent of Tongue River Basin area.

A study of "in-stream" values in the Tongue River by Bovee and others (1977) described streamflow in the Tongue River. They used duration curves for the state line and Miles City gaging stations (Figure 7.5), and noted the two curves were nearly identical, even though the size of the basin at Miles City is nearly five times larger than at the State line. This indicates that little additional discharge is accumulated in the lower river.

While most of the total discharge is from mountain snowmelt, annual hydrographs indicate that even below the reservoir, a large portion of the run-off occurs during only two months. The flow duration curve indicates that the mean annual discharge of 13.0 m^3/sec (461 ft^3/sec) at the Tongue River Dam is equalled or exceeded only 25 percent of the time. This means that for much of the year baseflow characteristics are quite important. At the

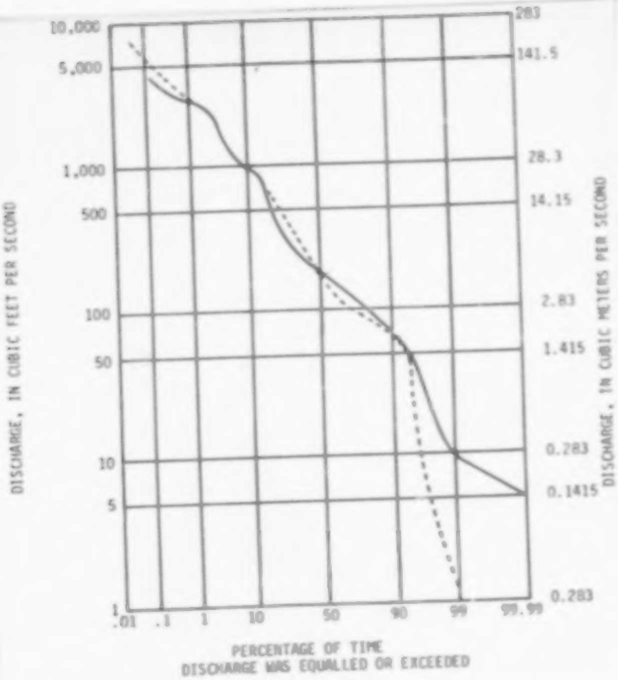


Figure 7.5 Flow duration curve for the Tongue River at state line (solid line) at Miles City (dashed line), 1961-1970 water years.

Reservation, baseflow is composed of water released from the reservoir plus local surface and groundwater inflow. NCRP studies focused on the determination of groundwater discharge rates to the Tongue River because of its importance for assessing coal strip mining impact on water resources.

Irrigation Depletions and Return Flows

Approximately 364 km^2 (90,000 ac) are irrigated along the Tongue River and tributaries upstream from Miles City, Montana (USGS, 1977). Of this 260 km^2 (64,300 ac) are in Wyoming, with the remainder in Montana. It is apparent that since most of the irrigated acreage is in Wyoming, irrigation consumptive use and return flows affect streamflow at the Reservation, even though these are modified by the Tongue River Reservoir. Most irrigation systems are the flooding types with some sprinkler systems installed in the past several years. Of the irrigated lands upstream from the Reservation, about 176 km^2 (43,500 ac) are under full water supplies, with 163 km^2 (40,200 ac) of this in Wyoming and 13 km^2 (3,300 ac) in Montana.

Accurate figures on irrigated acreage in Montana do not exist. However, studies by the DNRC in 1948 placed the area at 61 km^2 (15,000 ac) above the Northern Cheyenne Reservation boundary. Most of this area is along Otter Creek or other tributaries with limited water supplies. Information from the

Wyoming Water Planning Program indicates that estimated depletions for irrigation in the upper Tongue River are 440,370 m^3/km^2 (1.45 ac ft/ac) when there are full water supplies. Estimates of upper basin irrigation efficiencies are about 35 percent (i.e., 35 percent of the water applied for irrigation in the upper basin is consumptively used). Of the other 65 percent, 15 percent are irrecoverable losses while the remainder eventually reaches the Tongue River or surface tributaries as irrigation return flows. The schedule of return flows to the Tongue River is not well known. Engineers experienced with irrigation in the area estimate that 65 percent returns in the same month with the remainder distributed evenly over the next eight months (R. Cook, personal communication, 1977). At this rate, return flows by October and November are usually less than ten percent of the total groundwater discharge rate.

Tongue River Reservoir

The Tongue River Reservoir regulates stream flow for downstream irrigators. Recreation is an important secondary use. The reservoir, with a capacity of 83,600,000 m^3 (68,000 ac ft), is able to store about 19 percent of the average annual inflow. Active storage is about 49,200,000 m^3 (40,000 ac ft), all of which is obligated to downstream water users. Average annual evaporation from the reservoir was estimated to be about 102 cm (40 in) per year (USGS and State of Montana, 1977). Over an area of the reservoir, this amounts to about 12,300,000 m^3 (10,000 ac ft) per year.

The net effect of the reservoir is to decrease peak flows in spring and early summer and to increase late summer, fall, and winter flows. The total discharge released from the dam is less than the entering discharge because water is lost to evapotranspiration and groundwater seepage. The long-term reliability and quality of water supplies during the irrigation season is greatly enhanced by the reservoir.

The effect of the reservoir on low flows is of particular interest in mining impact assessments. Low flow frequency curves for the Tongue River at the state line above the Reservoir (Hopkins 1973), and the Tongue River at Tongue River Dam, are shown in Figures 7.6a and 7.6b. A comparison indicates that low flow discharges are greater below the dam than above the dam at recurrence intervals of greater than four years. Short term low flow events with little or no flow occur below the dam because of dam closures for maintenance or mechanical problems.

The Tongue River Dam was closed on two occasions in recent years. From October 30 to November 27, 1975, the dam was closed for a planned repair project. Water was pumped over the dam with one or two pumps to maintain

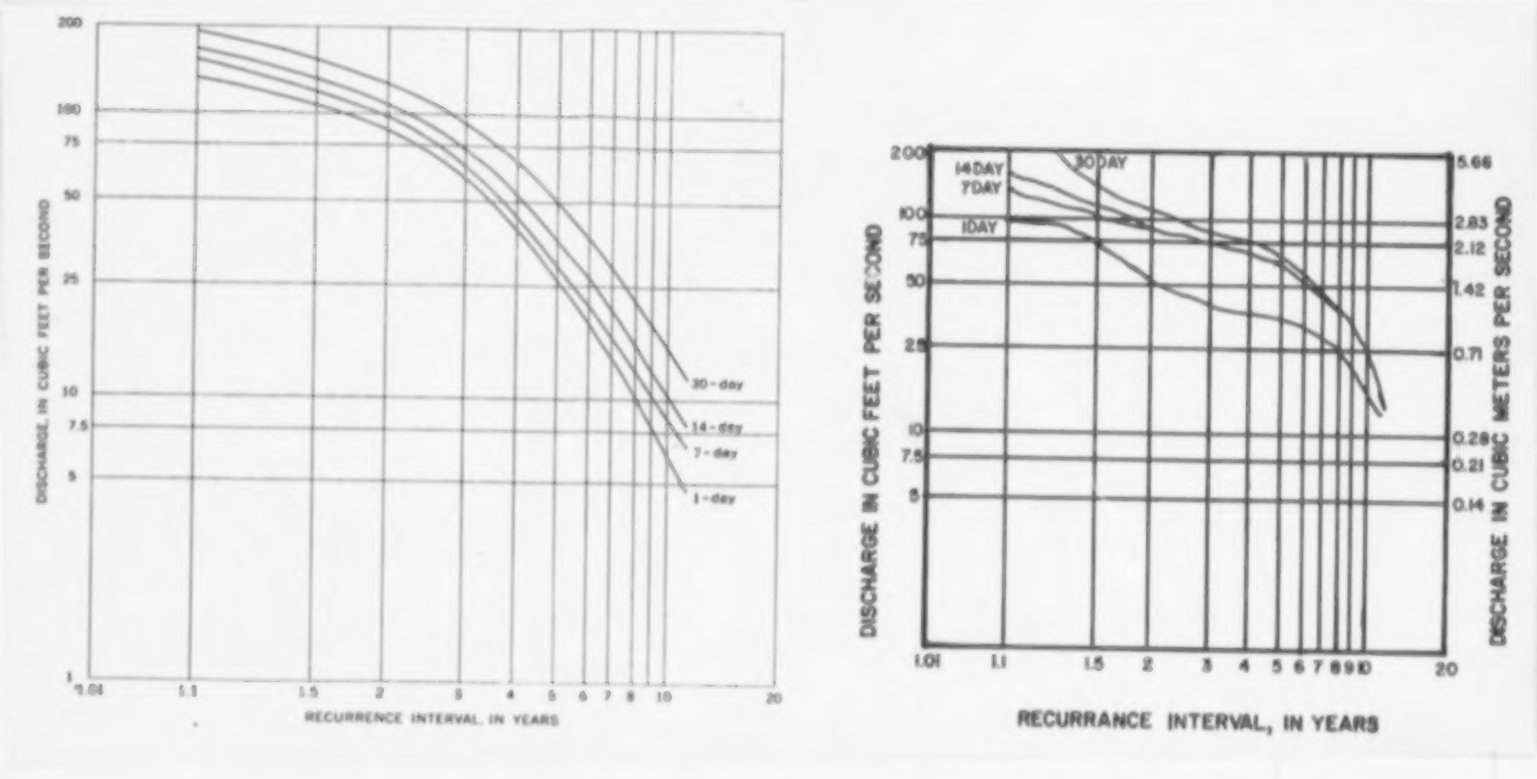


Figure 7.6. Low flow frequency curves for the Tongue River at the state line (a) and below the Tongue River Dam (b), 1961-1970 water years.

downstream fisheries. Seepage under the dam contributed additional water. Measured discharge at the dam or the USGS gaging station near the dam ranged from 0.34 to 0.96 m^3/sec (11.9 to 33.8 ft^3/sec). From June 19 to June 26, 1977, the dam was again closed, due to a broken gate cable. On June 24, NCRP staff saw no discharge from the reservoir and no pumps being used. Seepage beneath the dam formed pools of standing water in the channel but little actual flow was observed until just upstream from Birney. A large fish kill occurred immediately downstream from the dam.

Groundwater Discharge to the Tongue River

Introduction

Groundwater discharge is a small component of the total discharge of the Tongue River. It is composed of the composite discharge from bedrock, clinker, and alluvial aquifers to the river. Analyses of seepage run data indicated that ground water discharge to the Tongue River in Montana occurred at various rates along selected reaches depending on the proximity to higher precipitation zones and presence of geologic materials with good aquifer characteristics.

Seepage Run Data and Assumptions

During October-November 1975, the Tongue River Dam was closed for repairs and the flow past the dam was greatly reduced for about one month. The USGS coordinated a low-flow investigation of the Tongue River to quantify the ground water discharge contributions to the streamflow of the Tongue River downstream from the dam. The USGS, NCRP, Montana DNRC, and Department of Health and Environmental Sciences (DHES) made a total of 51 independent streamflow measurements at various points from the Tongue River Dam to the Yellowstone River.

A second comprehensive seepage run on the Tongue River was conducted in November 1977, by Morrison Maierle Inc., a contractor for the USGS, during a normal base-flow period. The NCRP participated by taking discharge measurements in the vicinity of the Reservation. A total of 27 measurements were taken over three days by three different crews giving somewhat variable inflow figures.

Effects of irrigation return flows were ignored in developing the groundwater discharge estimates after calculations indicated very small amounts could be expected in October and November. Return flow rates of 0.0008 m^3/sec/r km (0.047 ft^3/sec/r mi) are calculated for October and November.

A distinction between actual groundwater seepage and the effects of bank storage during the 1975 seepage run was not made in this analysis. NCRP stream gaging measurements taken before and after the dam closed indicated that the river stage may have decreased by 0.18 to 0.30 m (0.6 to 1.0 ft). Discharge records indicated that following dam closure, 12 to 18 days elapsed before river levels fell at the gaging station near Miles City.

Negligable amounts of precipitation fell during both the 1975 and 1977 seepage runs. Evaporative losses were ignored in developing the regional groundwater discharge estimates. An estimate of the average evaporation rate over the 290 river kilometers (180 river miles) from the Tongue River Dam to Miles City, assuming a 30.5 m (100 ft) wide stream, was calculated to be 0.121 m^3/sec/day (6.86 ft^3/sec/day) based on 1976 - 1977 evaporation data from the NCRP evaporation station at Tipi Ranch (E-1) during October and November. This rate amounts to negligible losses when measurements are taken over short to moderate stream distances, but could cause underestimation of seepage rates based on measurements taken over long distances. Daily temperature and evaporation rates vary widely during October and November.

Seepage Estimates Above and Below Brandenberg

The USGS gaging station near Brandenberg provided a convenient spot to divide the river in two reaches. The results of this analysis, and selected USGS stream flow records, are presented in Table 7.4.

The discharge values from the 1975 seepage run were simple averages of all measurements taken at the dam, Brandenberg and Miles City. USGS records from 1966 to 1975 were reviewed for the periods selected. During these periods, releases from the Tongue River Dam were relatively constant, discharges at the Brandenberg and Miles City stations were stable, surface tributary flow was stable, and precipitation records indicated little or no interference.

Variations in annual precipitation and groundwater recharge can certainly cause differences in net groundwater discharge from year to year; however, they are fairly uniform over this part of the basin. Any differences above and below Brandenberg should be preserved in the bottom line mean values.

The results indicate there was a substantial difference in ground water discharge to the Tongue River above and below Brandenberg. In the upper reach, all measurements showed a gain while in the lower reach there often were discharge losses. The magnitude of the difference varied, but the difference appeared to be consistent.

Seepage Differences Along Four Equal Reaches

The second step in analyzing the spatial variation of the groundwater discharge was to divide the Tongue River into four reaches. The results of this anaysis are presented in Figure 7.7. Each of the four reaches encompass about 76 river kilometers (47 river miles). It is felt in most cases that over this distance, the magnitude of expected groundwater inflow should exceed the magnitude of measurement error.

The values in Figure 7.7 are the unweighted and distance-weighted mean values of the seven to ten seepage measurements taken within that particular reach. The standard deviations of the mean inflow rates in Figure 7.7 generally increased in the downstream reaches. This may indicate that the numerous environmental and man-caused factors affecting streamflow had a more

TABLE 7.4. GROUNDWATER SEEPAGE RATES TO THE TONGUE RIVER UPSTREAM AND DOWNSTREAM FROM BRANDENBERG, MONTANA

Measurement Period	Average Discharge of Tongue River in cubic meters per second (and cfs)			Surface Tributary Discharges		Groundwater Discharge	
	T.R. Dam	Near Brandenberg	Near Miles City	Above Brandenberg	Below Brandenberg	Above Brandenberg	Below Brandenberg
River Kilometers	303	146 * 125	13				
River Miles	188.4	(90.6) (77.6)	8.1				
November, 1975 Ground water Discharge Study by USGS	0.566 (20)	2.60 (92)	3.17 (112)	0.212 (7.5)	.014 (0.5)	0.010 (0.58)	0.005 (0.29)
November, 1977 Seepage Run on Tongue River by Morrison-Maierle, Inc.	4.41 (156)	5.72 (202)	6.31 (223)	0.084 (3)	(0)	0.007 (0.39)	0.005 (0.30)
USGS Records Oct. 16-31, 1975	4.02 (142)	5.69 (201)	6.51 (230)	0.283 (10)	0.056 (2)	0.008 (0.44)	0.007 (0.39)
USGS Records Nov. 1-15, 1974	7.98 (282)	8.55 (302)	7.73 (273)	0.127 (4.5)	0.014 (0.5)	0.002 (0.14)	-0.007 (-0.41)
USGS Records Oct. 1-15, 1972	11.21 (396)	12.03 (425) *	10.70 (378)	0.169 (6)	0.028 (1)	0.004 (0.23)	-0.10 (-0.57)
USGS Records Oct. 16-25, 1969	4.50 (159)	5.89 (208) *	5.80 (205)	0.169 (6)	0.028 (1)	0.008 (0.44)	-0.001 (-0.04)
USGS Records Oct. 19-29, 1968	13.95 (493)	14.66 (518) *	14.18 (501)	0.169 (6)	0.028 (1)	0.003 (0.19)	-0.004 (-.20)
					Mean	+0.006 (+0.34)	-0.014 (-0.03)
				Standard Deviation		0.003 (0.16)	0.039 (0.38)

* The USGS gaging station near Brandenberg was relocated in October 1973.

Mean Ground Water Discharge in Cubic Meters per second per River Kilometer
(cubic feet per second per river mile)

Stream Reach	1975 Seepage Run Unweighted	1975 Seepage Run Distance Weighted	1977 Seepage Run Unweighted	1977 Seepage Run Distance Weighted
I. Dam to Birney Day Village Area	0.008 (0.48)	0.009 (0.49)	0.005 (0.26)	0.005 (0.28)
II. Birney Day Area to South of Brandenberg	0.015 (0.84)	0.011 (0.63)	0.022 (1.23)	0.018 (1.03)
III. Brandenberg Area to Pumpkin Creek	0.006 (0.35)	0.009 (0.53)	0.009 (0.52)	0.007 (0.40)
IV. Pumpkin Creek to Miles City	0.009 (0.56)	0.015 (0.82)	-0.003 (-0.15)	0.002 (0.11)
Entire Tongue River	0.010 (0.56)	0.011 (0.62)	0.008 (0.46)	0.008 (0.45)

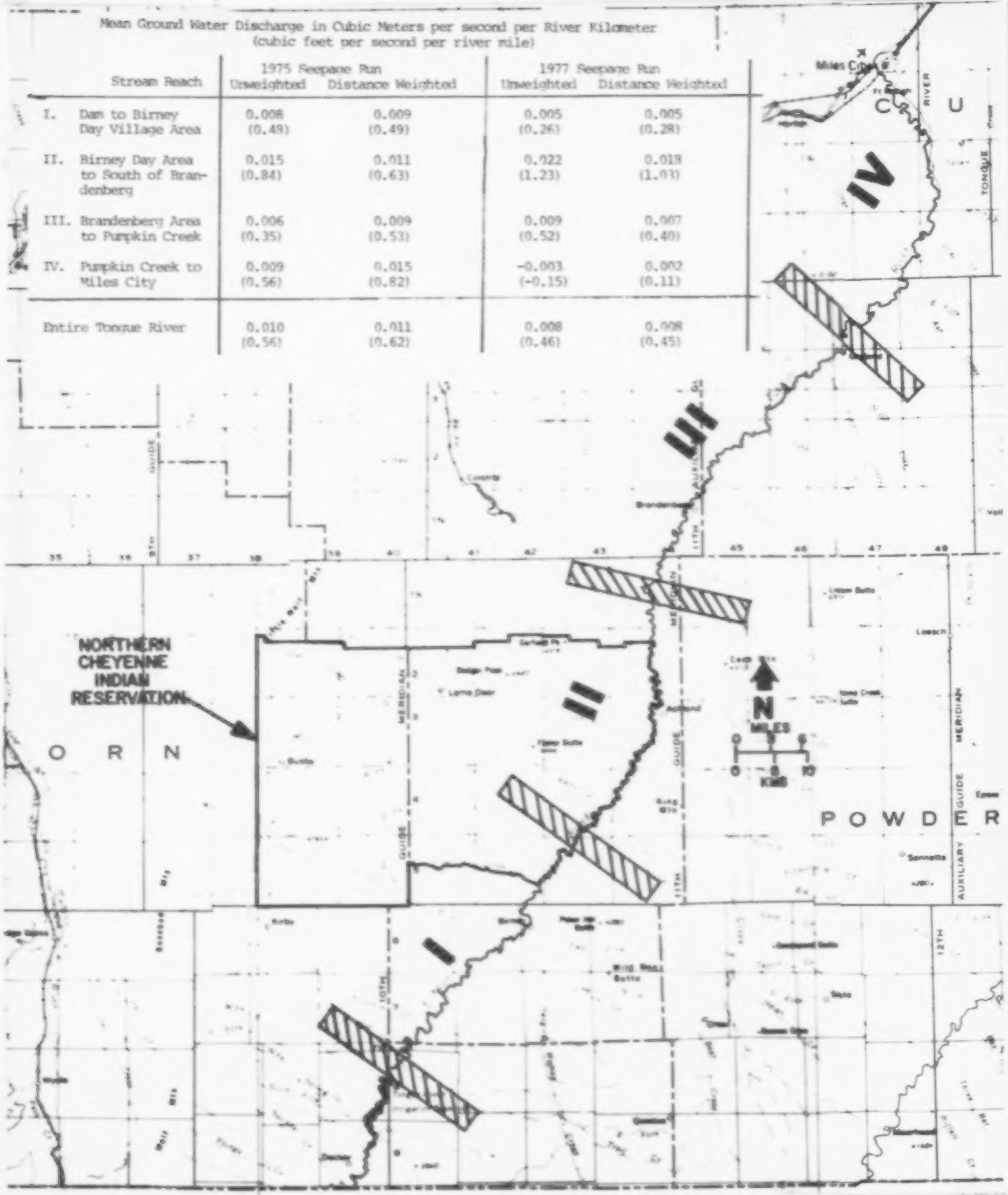

Miles City
C
U
RIVER
TONGUE
IV
III
Brandenberg
II
I
NORTHERN CHEYENNE INDIAN RESERVATION
O R N
POWDER
N
MILES
0 5 10
0 8 16
KMS
Lame Deer
Busby
Ashland
Birney
GUIDE
MERIDIAN
AUXILIARY
11TH
10TH
12TH

Figure 7.7. Groundwater seepage rates along four selected reaches of the Tongue River.

pronounced effect in the lower reaches. It may also indicate that the natural variations in groundwater inflow and other environmental forces are of greater magnitude than overall measurement errors. The four stream reaches are an arbitrary division; another method of division would yield somewhat different rates of inflow.

The groundwater discharge rate in Reach II , from Birney Day School to north of the Reservation, was generally the greatest. Reaches I and III had consistently moderate rates of inflow. Reach IV varied between apparently high rates at inflow to actual discharge losses in some cases. It is possible that the greater use of Tongue River water for irrigation in the lower reach may have caused diversions and return flows to influence seepage run results.

Hypotheses Accounting for Varying Groundwater Discharge Rates

Analyses of seepage data indicate that groundwater discharge to the Tongue River varies along its length from the Tongue River Reservoir to its mouth. Varying rates of precipitation and recharge to aquifers contributing groundwater discharge to surface waters, and variation in the extent, storage characteristics and hydraulic conductivity of these contibuting aquifers most likely accounts for the regional differences in groundwater discharge.

In most cases the largest amount of groundwater discharge to the Tongue River was measured along Reach II from Birney Day School to a point six miles north of the Reservation. The presence of high plateau regions of large extent containing thick, highly permeable clinker deposits of the Anderson burn on both the east and west side of the river, continuous coal seam aquifers beneath the plateau region and adjacent to and beneath river deposits, the presence of aquifer systems beneath the Knobloch coal and alluvium which are discharging water to the alluvium, a continous band of conductive Knobloch clinker which parallels the river on both sides along this reach, and a broad river valley filled with conductive alluvium, all provide large areas with the potential to receive recharge and move water to the river. One or more of these characteristics were not found in the other three reaches.

To the south of the Reservation along Reach I, only one of the two major aquifer systems is present. While the Anderson coal seam and related massive clinker deposits are exposed, the Knobloch Unit is buried, and not exposed to direct precipatation recharge in this area.

To the north of the Reservation, along Reaches III and IV, the Tongue River and its tributaries have eroded through the Tongue River Member and drain the Lebo Shale and Tullock Member of the Fort Union Formation. The lower portions of this formation have shalier deposits containing only thin coal seams exposed at the surface. Geologic deposits possessing good aquifer characteristics are fewer and of lesser quality. There may be proportionately more surface runoff and less groundwater recharge in this area.

Analyses indicate that the high country bordering Reach II receives 5 to 10 cm more precipitation on an annual basis than the surrounding country to the south and north. It is believed this combination of topography, geology and precipitation provides the mechanism for recharging, transmitting and discharging a larger volume of water through the groundwater system to the river than in these other areas.

Hydrology Along the Reservation

Streamflow Data for TR#1 and TR#2

Two gaging stations were operated on the Tongue River. Continuous water stage records were obtained at TR#2 from April 1976 to September 1979. Station TR#1, located about 8 kilometers north of Ashland, has a continuous water-stage record since July 1977. Monthly streamflow measurements made by the NCRP at these two sites were usually made on the same day, so that in effect, each set of measurements during baseflow periods constitutes a seepage run along the length of the Reservation.

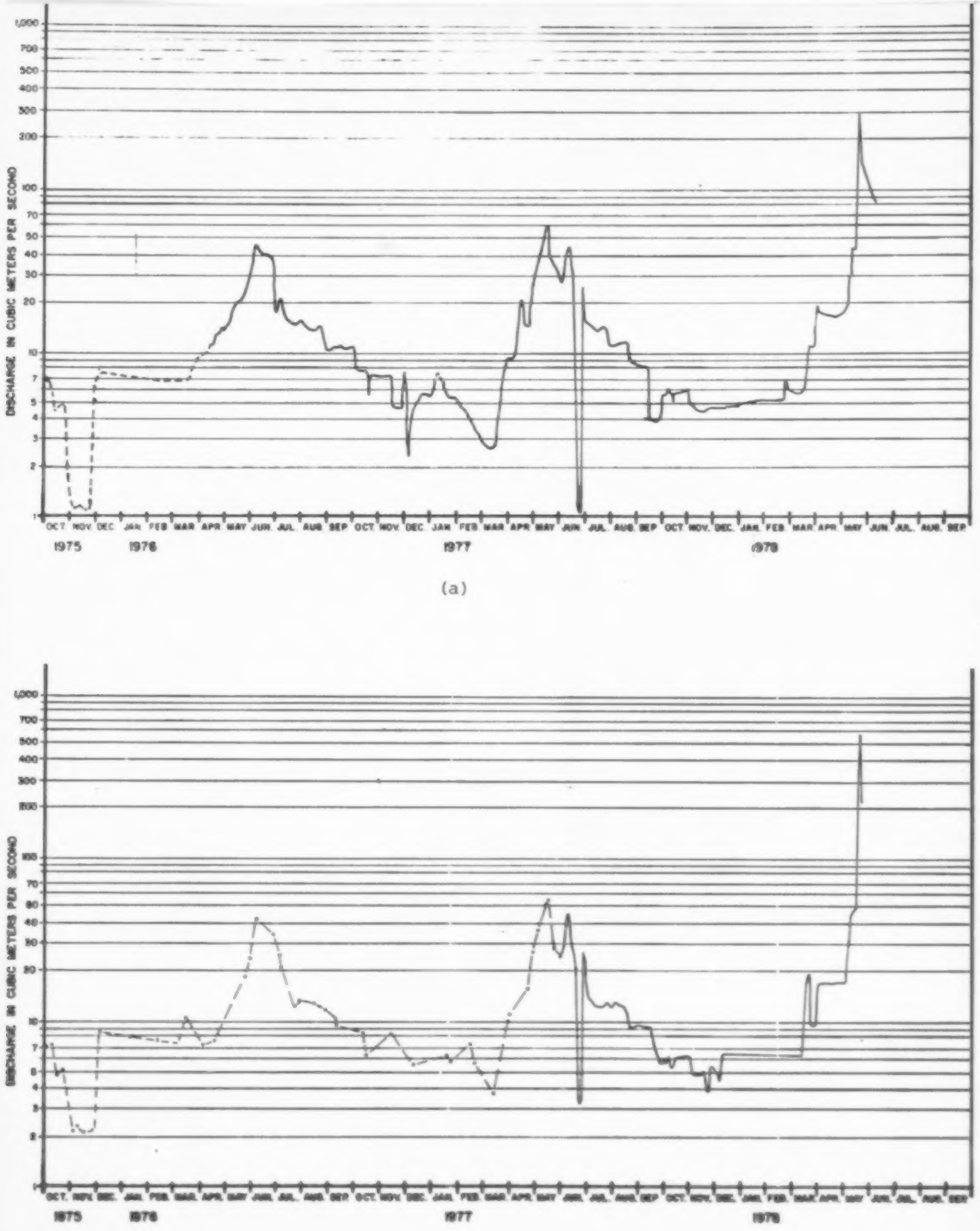
Hydrographs for TR#2 and TR#1 are presented in Figures 7.8a and 7.8b. Early NCRP data are based on periodic stage and discharge measurements, usually one to three measurements per month. The periods of continuous record are shown by a solid line.

Generally there is a gain in discharge in the downstream direction during the fall and winter months. In spring, TR#1 closely parallels the rising limb of the TR#2 hydrograph with a one day delay. Early summer months show the most net discharge gain downstream coinciding with the high percentage of annual precipitation during that period. Late summer months frequently show a discharge loss in the downstream direction due to consumptive uses of irrigation, evapotranspiration, and reduced surface runoff. The high peak that occurred in May 1978 was the largest flood on record of the Tongue River. Streamflow generally averaged slightly higher over the period of NCRP record than the long term average. Mean monthly discharge for the period of record at TR#1 and TR#2, and Tongue River Dam are given in Table 7.5.

For purposes of modeling coal surface mining impacts discussed in CHAPTER 8, it was desirable to use mean discharge figures for the NCRP gaging stations that were compatible with the period of water quality data collection. The mean discharge for the period, December 1975 through October 1977, was 13.53m^3/sec (487 ft^3/sec) at TR#2 and 14.66 m^3/sec (518 ft^3/sec) at TR#1. Other characteristic streamflows at TR#2 are the 50 percentile flow of 5.66 m^3/sec (200 ft^3/sec) from Figure 7.5, and the lowest flow of record which occurred during closure of the Tongue River Dam 1.13 m^3/sec (40 ft^3/sec) at TR#2.

Tongue River Tributaries

Cook Creek and Logging Creek are the principal drainages tributary to the Tongue River on the Reservation. Cook Creek flowed the entire duration of



(a)

(b)

Figure 7.8 Stream discharge hydrographs for stations TR #2 (a) and TR #1 (b).

TABLE 7.5. MEAN MONTHLY DISCHARGE FOR THE PERIODS OF RECORD AT TR #1 TR #2 AND TONGUE RIVER DAM.

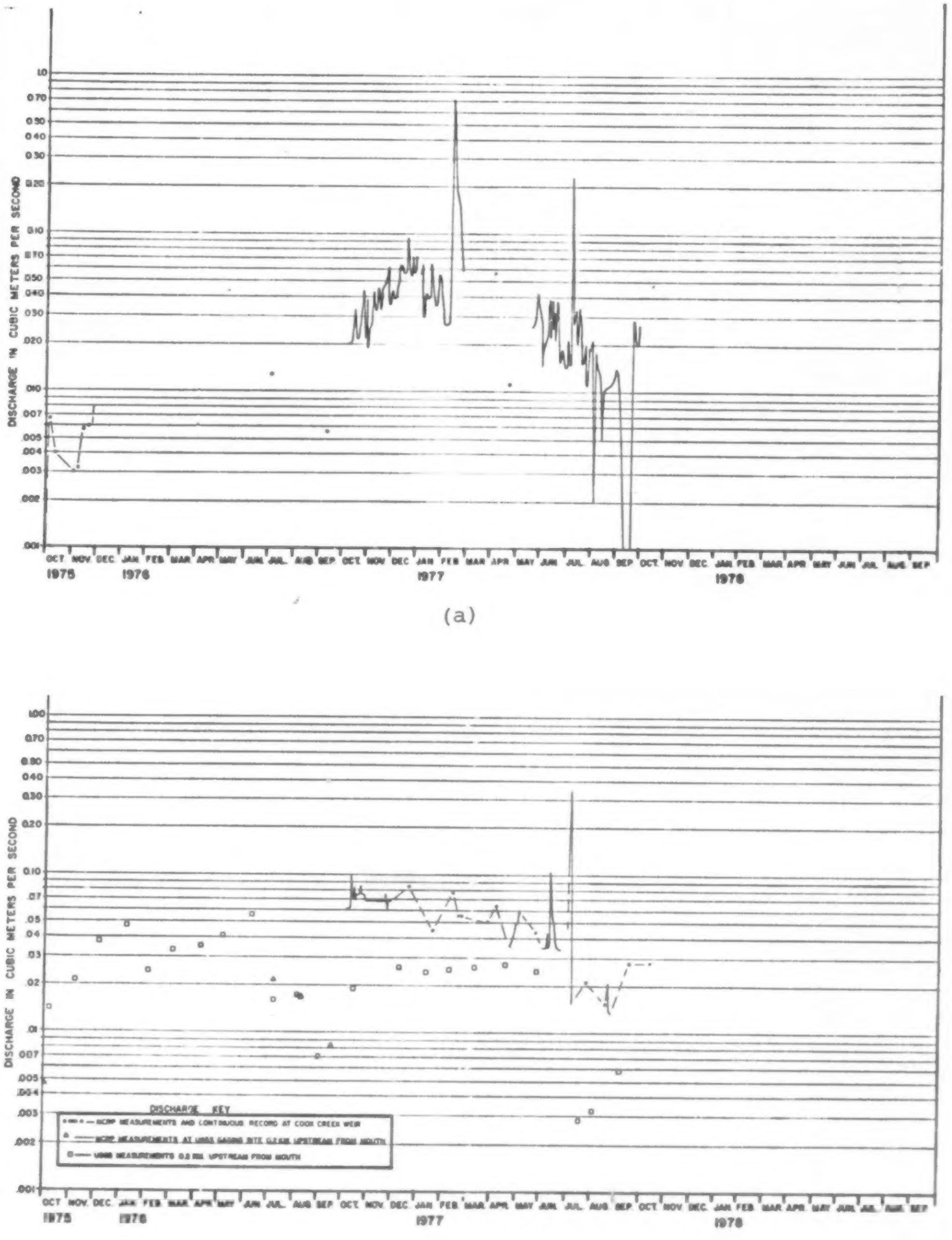
	WATER YEAR - 1976 - MEAN DISCHARGE IN CUBIC METERS PER SECOND											
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
Tongue R. Dam	4.33	1.15	7.24	6.91	6.65	7.33	10.5	20.3	38.0	15.9	13.0	9.54
TR #2							10.9	19.3	39.4	16.5	13.2	10.9
	WATER YEAR - 1977											
TR #2	7.58	5.25	4.33	6.17	4.39	4.53	15.3	38.9	25.7	13.7	10.7	6.17
TR #1									26.5	12.9	11.5	7.58
	WATER YEAR - 1978											
TR #2	5.77	4.66	4.76	5.11	5.54	8.06	17.5	81.8				
TR #1	5.94	5.06	6.02	5.71	6.51	9.28	16.8					

this investigation while Logging Creek dried up several times for a number of weeks.

Miscellaneous streamflow measurements and observations were made on Logging Creek from October 1975 to October 1976 when a 0.91m (3 ft) Parshall flume and gaging house were installed just upstream from the mouth. An estimate of the mean discharge over the 1976 and 1977 water years was calculated to be 0.021 m^3/sec (0.73 ft^3/sec). A hydrograph for the period of available record is presented in Figure 7.9a.

Miscellaneous streamflow measurements and observations on Cook Creek were made from October 1975 to October 1976. A 2.1 m (7 ft) Cipolletti weir and gaging house were installed upstream from the mouth in October 1976. An estimate of the mean discharge over the 1976 and 1977 water years was calculated to be 0.036 m^3/sec (1.26 ft^3/sec). A hydrograph for the period of available record is presented in Figure 7.9b.

The mean discharge of Otter Creek for the 1976 water year was obtained from USGS records (USGS, 1977). For water year 1977, continuous discharge records were not available at this writing; however, once per month discharge measurements were obtained with water quality data for the station at Ashland, Montana. Once per month measurements for four months were adjusted to mean



(a)

(b)

Figure 7.9. Stream discharge hydrographs for Logging Creek #1 (a) and Cook Creek #1 (b).

monthly flow estimates using available RBC #1 station data and techniques described by the USGS (Riggs, 1972). For the eight months without corresponding RBC #1 daily discharge data, the once per month measurement was assumed to represent the monthly mean. This technique gave an estimate of the mean discharge for the 1976 to 1977 water years of 0.114 m^3/sec (4.02 ft^3/sec).

There is an additional 816 km^2 (315 mi^2) ungaged watershed area between TR#2 and TR#1 that contributes surface runoff to the Tongue River primarily during snowmelt and thunderstorms. An estimate of the runoff from the ungaged watershed area was made using a coefficient of 0.02 derived from the ratio of the mean discharge for the 1976 and 1977 water years to the watershed areas of Cook Creek and Logging Creek. The runoff coefficients for Logging Creek and Cook Creek were found to be identical, indicating a close correlation between drainage area and discharge for Tongue River tributaries along the Reservation.

Applying the runoff coefficient to the ungaged watershed area on both sides at the Tongue River between TR#1 and TR#2 (minus Cook Creek, Logging Creek and Otter Creek), total mean runoff for the 1976 and 1977 water years was estimated to be 0.176m^3/sec (6.21 ft^3/sec).

Groundwater Discharge to the Tongue River Along the Reservation

Data for this evaluation came from the 1975 and 1977 seepage runs and also from monthly streamflow measurements at NCRP stations TR#1 and TR#2. Several other special seepage runs were conducted by the NCRP along the Reservation. Groundwater discharge along the Reservation averaged somewhat less than that calculated in the regional analyses for Reach II, and comprised 16 percent of the discharge at TR#1 during the baseflow periods measured.

The NCRP conducted several seepage runs at different times of the year to quantify varying groundwater discharge rates. Late fall and winter measurements were best for assessing baseflow seepage rates.

A summary of synoptic stream flow measurements taken at TR#2 and TR#1 is presented in Table 7.6. The measurement pairs used in this table are from special seepage runs previously discussed or from monthly discharge measurements. Precipitation was negligible during these measurements and evaporation was estimated in two instances. Tributary contributions had to be estimated in several cases, but do not affect the final estimated inflow range. The mean value of 0.001 m^3/sec/r km (0.55 ft^3/sec r mi) was calculated to be the average baseflow ground water discharge rate to the Tongue River over the period of data.

ROSEBUD CREEK

Basin Features and Characteristics

Rosebud Creek has its headwaters in the Wolf Mountains, immediately southwest of the Northern Cheyenne Reservation. The Wolf Mountains are not

TABLE 7.6. GROUNDWATER INFLOW TO THE TONGUE RIVER ALONG THE NORTHERN CHEYENNE RESERVATION, MONTANA

NCRP Gaging Dates	Average Discharge of Tongue River in Cubic Meters per second (cms) and (cfs)		Surface Tributary Discharge in cms (and cfs)	Evaporative Losses in cms (and cfs)	Net Groundwater Discharge in cms per river kilometer (and cfs per mile)
	TR #2 Below Birney	TR #1 Below Ashland			
River Kilometers	244	168			
River Miles	151.8	104.5			
10-16-75	4.41 (156)	4.90 (173)	0.170* (6.0)	0.054* (1.9)	0.005 (0.27)
11-06-75	1.14 (40.3)	2.17 (76.7)	0.136 (4.8)	(neg)	0.012 (0.67)
11-19-75	1.14 (40)	2.12 (75.0)	0.161 (5.7)	(neg)	0.011 (0.67)
12-14-76	4.47 (158)	5.55 (196)	0.170* (6.0)	(neg)	0.012 (0.68)
1-24-77	5.52 (195)	5.83 (206)	0.170* (6.0)	(neg)	0.002 (0.11)
2-19-77	6.34 (224)	7.22 (255)	0.170* (6.0)	(neg)	0.009 (0.53)
3-18-77	2.66 (94)	3.71 (131)	0.170* (6.0)	(neg)	0.012 (0.66)
10-14-77	4.53 (160)	5.69 (201)	0.136 (4.8)	0.054 (1.9)	0.014 (0.81)
11-02-77	5.38 (190)	6.25 (221)	0.136 (4.8)	(neg)	0.010 (0.55)

MEAN	(0.010) (0.55)
STANDARD DEVIATION	(0.004) (0.22)

* Value estimated from available data

true mountains, but are a sedimentary upland ranging to a maximum elevation of 1,647 m (5,400 ft). There are minor climatic differences between the headwater area and downstream regions. Rosebud Creek may be classed as a prairie stream in its entirety. A significant snowpack generally does not develop in the headwaters. Rosebud Creek empties into the Yellowstone River near Rosebud, Montana, over 330 river kilometers (205 river miles) north of its headwaters. It runs through the Northern Cheyenne Reservation for 112 river kilometers (70 river miles) in its upstream reach. Two principal perennial streams are tributary to Rosebud Creek from the Reservation: Lame Deer Creek and Muddy Creek. A number of smaller drainages contribute surface water for much of the year. Several additional surface tributaries enter Rosebud Creek on the Reservation, although most of their drainage areas lie to the west on the Crow Indian Reservation. Runoff volume is normally greatest following spring snowmelt and early summer rainfall. Baseflow conditions prevail throughout late summer, fall, and winter.

Valley elevations on the Reservation range from 1,140 m (3,750 ft) at the southern end to 960 m (3,150 ft) at the northern end. A series of sharply incised drainages dissect the upland plateaus and benches on either side of Rosebud Creek Valley with a scenic array of timbered hills, buttes, and ridges.

The valley itself is approximately one kilometer (0.60 mi) in width and used primarily for cattle ranching operations. Alfalfa, hay, and grain are the principal crops. Very few flood irrigation systems have been developed on the Reservation or upstream. Most alfalfa fields and riparian vegetation receive sub-irrigation for a substantial part of the growing season.

Mean annual precipitation in the Rosebud Creek basin varies from 43 cm (17 in) at elevations of 1,219 m (4,000 ft) in the headwaters area to 30 cm (12 in) at lower elevations near the mouth.

A graph of mean stream discharge versus percent basin area (Figure 7.10) gives an indication of the watershed characteristics of the basin. It shows that most or all of the mean annual discharge for the 2 years of record is accumulated in the upper half of the basin above the Colstrip gaging station. Data from NCRP gaging stations indicate that about 98 percent of the mean annual discharge at the mouth occurs at the northern Reservation boundary and that 85 percent of the total discharge accumulates between southern and northern Reservation boundaries. Consumptive uses by irrigation, riparian vegetation and possibly subsurface outflow cause streamflow depletions in the lower half that are generally not augumented to any measurable degree by additional surface water discharge. The mean annual discharge for the two years of available record was 0.984 m^3/sec (34.8 ft^3/sec) at the mouth near Rosebud, Montana, and 0.962 m^3/sec (34.0 ft^3/sec) at the northern Reservation boundary. Local residents recall at least two years of zero flow during the past 50 years. The largest flood of record occurred in the basin during May 1978, following 12 to 18 cm (5 to 7 in) of rain during a two-day period.

There are no major reservoirs on the mainstream of the Rosebud, but numerous small ponds on tributary drainages are used by livestock. Two types of irrigation occur along Rosebud Creek. In the upper reach, wild flooding

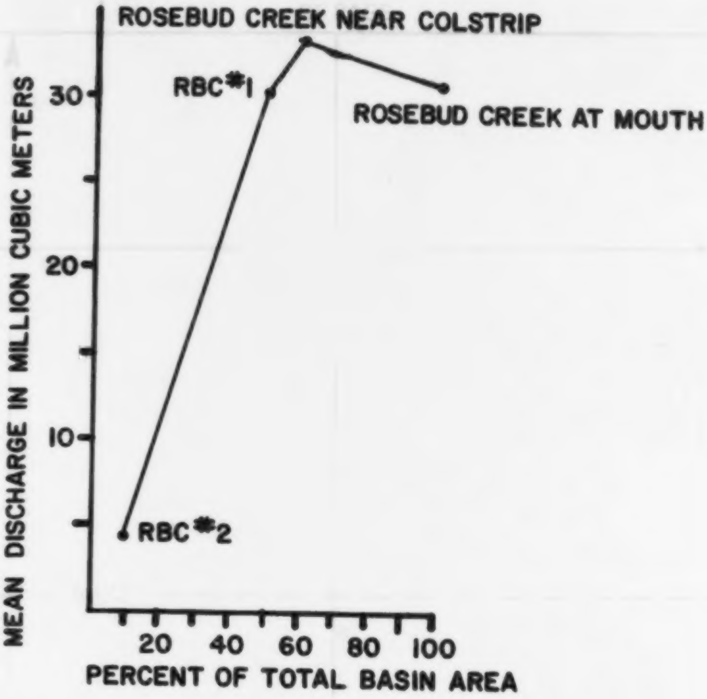


Figure 7.10. Mean discharge versus the percent of total basin area for Rosebud Creek, water years 1976 and 1977.

of hay and pasture land from tributary drainages takes place in spring and early summer, but very little diversion or pumping takes place. In the lower half, diversions and pumping from the creek are common. USGS records (1977) indicate approximately 8 km^2 (2,000 acres) are irrigated above the mouth of Rosebud Creek and only 3.2 km^2 (800 ac) irrigated above the gaging station near Colstrip.

As along the Tongue River, riparian vegetation and deep-rooted species in adjoining bottom lands consume water in the growing season. Numerous domestic wells draw water from the alluvium of the Rosebud Creek Valley, both on and off the Reservation.

The type, extent and location of geologic deposits influence ground water capture, storage, and movement to Rosebud Creek. Extensive clinker deposits of two hydrogeologic units are present in the head waters and Reservation area. These deposits appear to provide more groundwater to springs, small surface tributaries, and Rosebud Creek than the near surface geologic deposits to the north of the Reservation.

Gaging Stations on Rosebud Creek

There are two USGS continuous recording stations on Rosebud Creek. Both are downstream from the Reservation. One station, Rosebud Creek at the mouth, near Rosebud, Montana (USGS Station #629603), has been in operation since October, 1974. In the past, two other stations have been operated near the site of the present one: Rosebud Creek near Rosebud (USGS Station #0629550) from July 1938 to June 1943; and Rosebud Creek near Forsyth (#0628600) from June 1947 to November 1953. The drainage areas at these three stations are 3,372, 3,090 and 3,463 km^2, respectively. Another continuous recording station has been operated by the USGS since October 1974 at Rosebud Creek near Colstrip (USGS Station #629250). It has a drainage area of 2,069 km^2 and is located about 12 km north of the Reservation (Figure 7.1).

The Northern Cheyenne Research Project began its hydrologic investigation in October 1975, with selection of sites for surface water gaging stations on Rosebud Creek near the south and north Reservation boundaries. Intermittent outside staff gage readings began in April 1976. Monthly meter measurements were also made within one or two days on all principal tributaries of Rosebud Creek: Lame Deer Creek, Muddy Creek, Davis Creek, Thompson Creek, Corral Creek, and Trail Creek. In June 1977, continuous recording servomanometer water level recorders were installed at the two Rosebud Creek gaging stations; RBC #1, at the northern downstream boundary and RBC #2 at the southern, upstream boundary. A 2.13 m (7 ft) Cipolletti weir was installed on Lame Deer Creek near the confluence with the Rosebud, and continuous water stage records have been taken since early 1977. A cement trapezoidal weir and water stage recorder were installed on Muddy Creek in October 1976. Available records are intermittent due to beaver flooding of the weir.

Groundwater Discharge to Rosebud Creek

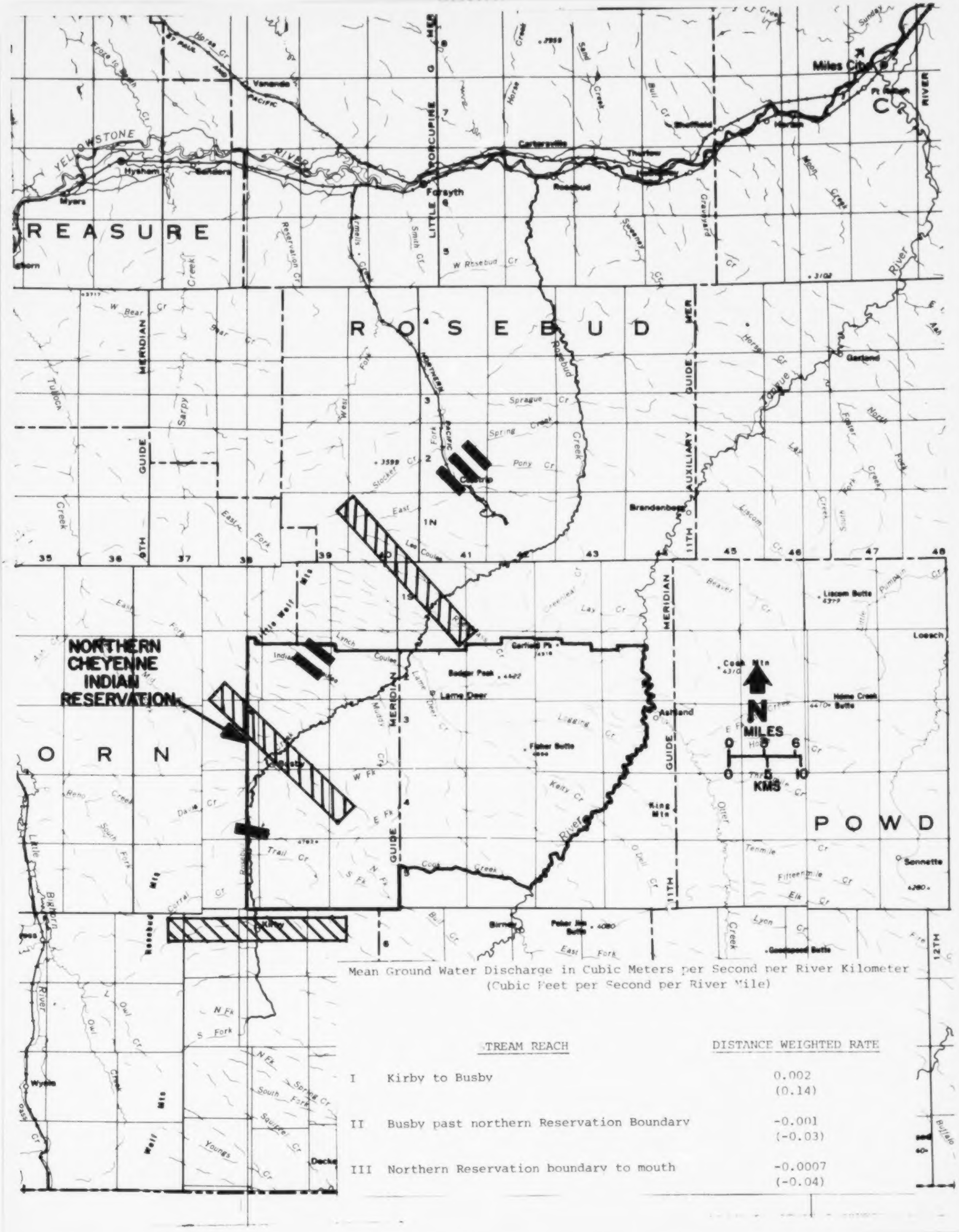
Headwaters to the Mouth

The U.S. Geological Survey, through its contractor, Morrison-Maierle, Inc., conducted a seepage run over the entire length of Rosebud Creek from October 31 through November 3, 1977. The NCRP participated by making streamflow measurements on the Reservation. Analyses of the results provide insight to the hydrology of Rosebud Creek.

The data from this seepage run showed that Rosebud Creek generally gained in discharge throughout its upper half, and lost flow through out its lower half. More detailed analyses indicated that Rosebud Creek could be divided into three characteristic reaches for discussion purposes, as shown in Figure 7.11.

Reach I, extending from Kirby to Busby, Montana, is 53 river kilometers in length (32 miles). It is characterized by continual streamflow gain from both surface water tributaries and groundwater discharge. Surface water tributaries along the Northern Cheyenne Reservation discharged a total of 0.101 m^3/sec (3.55 ft^3/sec).

When the effects of surface tributaries are accounted for, the mean distance-weighted groundwater discharge rate was 0.002 m^3/sec/r km (0.14 ft^3/sec/r mi). Rosebud Creek discharge increased from 0.235 m^3/sec (8.323 ft^3/sec) at Kirby to 0.461 m^3/sec (16.3 ft^3/sec) at Busby.


REASURE
ROSEBUD
ORN
POWD
NORTHERN CHEYENNE INDIAN RESERVATION
YELLOWSTONE RIVER
Miles City
Forsyth
Rosebud
Hysham
Myers
Cartersville
Lame Deer
Busby
Kirby
Ashland
Birney
Brandenberg
I
II
III
N
MILES
0 3 6
0 5 10
KMS

Mean Ground Water Discharge in Cubic Meters per Second per River Kilometer
(Cubic Feet per Second per River Mile)

	STREAM REACH	DISTANCE WEIGHTED RATE
I	Kirby to Busby	0.002 (0.14)
II	Busby past northern Reservation Boundary	-0.001 (-0.03)
III	Northern Reservation boundary to mouth	-0.0007 (-0.04)

Figure 7.11. Groundwater seepage rates along three selected reaches of Rosebud Creek.

Reach II extends from Busby to approximately 35 km (14 mi) north of the northern Reservation boundary for a length of 88 river kilometers (55 river miles). This reach was characterized by a downstream gain in discharge that could be entirely accounted for by the surface tributary contributions of Muddy and Lame Deer Creeks. Net groundwater discharge was effectively zero within the reach. A slight loss of 0.001 m^3/sec/r km (0.03 ft^3/sec/r mi) was indicated within the Reservation once the contributions of Muddy and Lame Deer Creeks were subtracted. The discharge of Rosebud Creek was 0.461 m^3/sec (16.3 ft^3/sec) at the start of Reach II and 0.538 m^3/sec (19.0 ft^3/sec) at the downstream end below the Reservation.

Reach III continues downstream from Reach II to the confluence with the Yellowstone River, a distance of 154 river kilometers (95.8 river miles). This reach was generally characterized by a downstream loss in streamflow. There was essentially no additional surface tributary contribution. Discharge at the upstream end of the reach was 0.538 m^3/sec (19.0 ft^3/sec) on 10/31/77, while discharge at the mouth was 0.385 m^3/sec (13.6 ft^3/sec) on 11/2/79. Only four of ten current meter measurements indicated small amounts of downstream gains in discharge. Evaporation rates were small. There was no record of stream diversions or withdrawals indicating the possibility that Rosebud Creek was influent throughout portions of this reach. The loss rate of streamflow in this reach was 0.0007 m^3/sec/r km (0.04 ft^3/sec/r mi).

Hypotheses Accounting for Varying Groundwater Discharge

Groundwater discharge rates to Rosebud Creek were found to vary along its length during the period of the seepage run. The single seepage run provided only preliminary data but was sufficient to indicate general trends. Groundwater discharge rates measured during the fall most likely represent base flow rates, with higher rates possible during spring and early summer. As in the Tongue River, hydrologic parameters such as varying rates of precipitation and recharge to aquifers contributing to groundwater discharge and variations in the extent, storage characteristics, and hydraulic conductivities of the contributing aquifers most likely accounts for the regional differences in groundwater discharge to Rosebud Creek. These factors vary significantly along the length of Rosebud Creek, and correlate with groundwater discharge rates.

The higher elevation areas in the Wolf Mountains and on the Reservation bordering Reach I receive more annual precipitation than the watershed area downstream, as discussed in CHAPTER 4. Lower evaporation rates at higher elevations may also make more water available for recharge to aquifers.

A second factor which affects the groundwater inflow in Reach I is caused by the extent and type of geologic deposits. Extensive aquifer systems are present to trap, store, and transmit groundwater to Rosebud Creek in Reach I. The headwaters of Rosebud Creek are in an area of extensive coal and clinker deposits formed by the burning of the Roland, Anderson, Dietz, Canyon, and Wall coal seams of the Tongue River Member of the Fort Union Formation. The relatively thick, continuous, and permeable nature of these aquifer systems is conducive to groundwater storage and movement to Rosebud Creek. The Wall clinker in this area averages 30 m (100 ft) thick while the Canyon clinker is about 18 to 24 m (60 to 80 ft) thick. Physiographically, both the higher elevation terrain and the extensive clinker deposits are in close proximity to the Rosebud Creek Valley in Reach I. Many of the hills forming the flanks of the valley and tributary drainages are formed by massive Wall and Canyon clinker deposits. This feature indicates that groundwater recharge may more readily reach Rosebud Creek compared to areas downstream where the higher elevation, precipitation zones and clinker deposits are further removed from the valley.

Along Reach II, the 1977 seepage run indicated that little or no groundwater discharge to Rosebud Creek was occurring. It appears that most groundwater potentially available to Rosebud Creek from upland areas is reaching the creek through the surface drainages of Muddy and Lame Deer Creeks. From the Busby area to near the mouth of Muddy Creek, the clinker outcrops of the Wall, Canyon, Pawnee, and Sawyer seams are three to five km from Rosebud Creek Valley to the southeast (Figure 5.27). The west fork of Muddy Creek and its tributaries probably capture much of the available groundwater discharge. To the northwest of Rosebud Creek little clinker is present from the Busby area, until the Lynch Coulee vicinity near the northern Reservation boundary. The coal seams in this area are generally thinner with more sandstone and shale deposits than the area southeast of Rosebud Creek. The lack of extensive clinker deposits in close proximity to the creek may be the most important factor related to the apparent decrease in groundwater discharge directly to Rosebud Creek in Reach II.

In Reach III of Rosebud Creek, seepage run results indicated that surface water discharge generally declined in the downstream direction. Knapton and McKinley (1977) stated in their report on water quality and streamflow characteristics of southeastern Montana that at least part of the streamflow losses in the middle and lower portions of Rosebud Creek seem to be the result of subsurface outflow from the stream. They further indicated that basin geology was primarily responsible for such conditions. Rosebud Creek leaves the Tongue River Member 20 km (12 mi) below the start of Reach III, and traverses the Lebo Shale and Tullock Members of the Fort Union Formation, and the Cretaceous Hell Creek Formation before emptying into the Yellowstone River. The absence of continuous coals, thick sandstone, or clinker in these units most likely does not provide adequate avenues for substantial recharge and water movement to the creek.

The watershed of Rosebud Creek, bordering Reach III, is lower in elevation than the other reaches and is in the 30 to 36 cm (12 to 14 in) precipitation zone, thus, affording less water available for groundwater recharge.

Stream Discharge Along the Reservation

Stream Flow Data for RBC#1 and RBC#2

Two stream gaging stations were operated in Rosebud Creek. Station RBC#2, near Kirby, Montana, has continuous water stage records since June 1977. Station RBC#1, north of Lame Deer, has continuous water stage records since May 1977. Monthly discharge measurements at those two sites were usually made within one day of each other so that each pair of measurements during baseflow periods constitutes a seepage run over that reach when surface tributaries are accounted for.

Hydrographs for NCRP gaging stations RBC#1 and RBC#2 are presented in Figures 7.12a and 7.12b. Discharge data up to June,1977 are based on periodic stage and discharge measurements, usually one to three per month. Continuous records are represented by a solid line on the graphs.

Generally, there is a considerable gain in discharge between RBC#2 and RBC#1 throughout the year. Mean annual discharge approximately doubles between the south and north Reservation boundaries. Greatest discharge gains occur in winter, spring, and early summer. Smaller gains in late summer can probably be attributed to consumptive uses by evaporation, riparian vegetation, subirrigated fields, and less precipitation. The annual low flows during the two years of record both occurred during September at RBC#1 and RBC#2. Discharge moderately increased in October, due to decreased evapotranspiration rates and increased precipitation. Mean monthly discharge for the period of record at RBC#1 and RBC#2 is shown in Table 7.7.

TABLE 7.7. MEAN MONTHLY DISCHARGE FOR THE PERIOD OF RECORD AT RBC #1 AND RBC #2

Water Year 1977 - Discharge in Cubic Meters Per Second

	O	N	D	J	F	M	A	M	J	J	A	S
RBC #2									0.76	0.36	0.19	0.16
RBC #1									1.38	0.90	0.50	0.38
Near Colstrip	1.09	1.13	1.15	1.02	1.78	1.86	2.10	2.32	1.99	1.36	0.61	0.48

Water Year 1978

	O	N	D	J	F	M	A	M	J	J	A	S
RBC #2	0.24	0.28	-	0.22	0.30	0.78	1.30	4.09				
RBC #1	0.54	0.59	0.60	0.56	0.57	1.45	1.44	9.23				

Rosebud Creek Tributaries

Muddy Creek and Lame Deer Creek are the principal tributaries to Rosebud Creek on the Reservation. Both are perennial streams deriving most of their discharge from springs and groundwater baseflow. Peak flows occur during periods of rapid spring snowmelt or large early summer thunderstorms. Low flows occur during late summer and early fall during periods of high evapotranspiration rates and low precipitation.

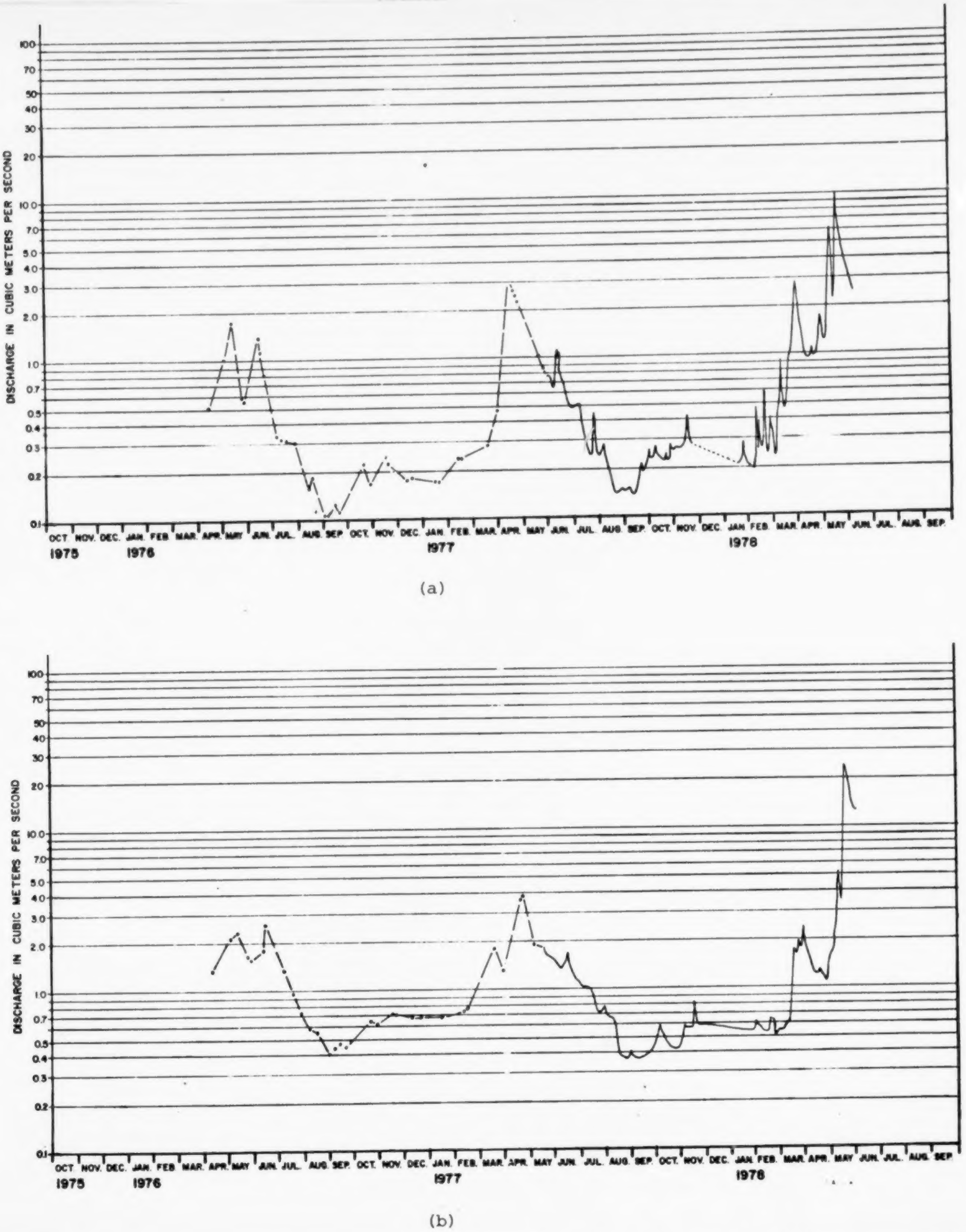


Figure 7.12. Stream discharge hydrograph for stations RBC #2 (a) and RBC # 1 (b).

A total of 14 streamflow measurements were made on Muddy Creek, primarily on a monthly basis, starting in May 1976. A cement bag trapezoidal weir and gaging house were installed one kilometer upstream from the mouth in March 1977. Available water stage records are intermittent, due to the flooding of the weir by downstream beaver dams. An estimate of the mean discharge for the 1976 and 1977 water years was calculated to be 0.106 m^3/sec (3.76 ft^3/sec). The estimate assumes that the single discharge measurement per month is equivalent to the mean for that month for water year 1977. The mean for water year 1976 was estimated by multiplying the 1977 water year mean by a coefficient of 0.93 derived from the ratio of the mean flow for the two years at RBC#2.

A total of 15 current meter measurements were made on Lame Deer Creek between May 1976 and November 1977, primarily on a monthly basis. A 2.13 m (7 ft) Cipoletti weir and gaging house were installed just above the mouth, north of Lame Deer and were completed on April 7,1977. The estimated mean discharge for the 1976 and 1977 water years is 0.071 m m^3/sec (2.50 ft^3.sec). The hydrograph for the period of record is shown in Figure 7.13.

The four other perennial tributaries of Rosebud Creek on the Reservation are Trail Creek, Davis Creek, Thompson Creek, and Corral Creek. Trail Creek originates wholly on the Reservation while the other three have most of their drainage areas on the Crow Reservation to the west. These creeks, while varying in watershed area, have basin characteristics similar to Lame Deer and Muddy Creeks. During most of the year, their discharge is derived principally from springs and groundwater baseflow.

Nine to sixteen current meter measurements were made on each of these tributaries from July 1976 through November 1977. An estimate of the mean discharge for the 1976 and 1977 water years by stream is given in Table 7.8.

The mean discharge of all principal surface tributaries to Rosebud Creek on the Reservation for the 1976 and 1977 Water Years was estimated to be 0.414 m^3/sec (14.6 ft^3/sec). The low flow period selected for modeling mining impacts on Rosebud Creek is September 1976, when the sum of the surface tributary flows was 0.311 m^3/sec (11.0 ft^3/sec).

Groundwater Discharge to Rosebud Creek Within the Reservation

Groundwater discharge rates to Rosebud Creek on the Reservation were estimated from three seepage runs conducted in October 1977 and from monthly streamflow measurements at NCRP stations RBC#1 and RBC#2. Detailed data for the seepage runs are presented in Table 7.9. Tributaries were gaged by current meter on either October 26 or November 1, 1977. Tributary discharge was assumed to be constant for all three seepage runs. Evaporation rates at Tipi Ranch for October 1977 were used. Channel geometry and travel time in Rosebud Creek were derived from NCRP gaging station data.

Precipitation records show that approximately 0.5 cm (0.20 in) of rain fell between October 30 and 31, 1977. This may have caused the somewhat

TABLE 7.8 MEAN DISCHARGE OF SEVERAL ROSEBUD CREEK TRIBUTARIES

	m^3/sec	ft^3/sec
Corral Creek	0.128	4.53
Trail Creek	0.026	0.91
Thompson Creek	0.062	2.19
Davis Creek	0.021	0.072
TOTAL	0.237	8.35

TABLE 7.9 GROUNDWATER SEEPAGE RATES TO ROSEBUD CREEK UPSTREAM AND DOWNSTREAM FROM BUSBY, MT.

Station	River Kilometer (mile)	Kilometer Change (mileage)	Streamflow Measurements Cubic meters per second and (cfs)			Surface Tributary -Discharge cms (cfs)	Evaporation +Losses cms(cfs)	Groundwater = Water Discharge cms (cfs)			Groundwater Discharge Rate (cubic meters per second per river kilometer) (cfs per mile)			Mean Rates cms/km (cfs/ mile)
			10/17	10/27	10/31			10/17	10/27	10/31	10/17	10/27	10/31	
RBC #2 at Res. line near Kirby, Mt.	288 (179)		0.229 (8.10)	0.201 (7.10)	0.249 (8.80)									
		45 (27.8)				0.101 (3.56)	0.004 (0.15)	0.068 (2.39)	0.116 (4.09)	0.116 (4.09)	0.002 (0.09)	0.003 (0.15)	0.003 (0.15)	Mean 0.003 (0.13)
Busby, Mt. above sewage lagoons	243 (151.2)		0.393 (13.9)	0.413 (14.6)	0.461 (16.3)									
		67 (41.6)				0.100 (3.49)	0.007 (0.26)	-0.004 -0.13)	0.042 (1.47)	-0.029 (-1.03)	-0.0001 (-0.003)	0.001 (0.04)	-0.0004 (-0.025)	0.0002 (0.004)
RBC #1 at Res. line near Lame Deer, Mt.	176 (110)		0.481 (17.0) (from stage re-corder)	0.546 (19.3)	0.524 (18.5)									
											Weighted Averages			
TOTALS		112 (69.4)				0.200 (7.05)	0.012 (0.41)	+0.064 +2 26)	+0.158 (+5.56)	0.087 3.06	+0.0007 (0.034)	+0.0022 (0.08)	0.001 (0.05)	0.0012 (0.055)

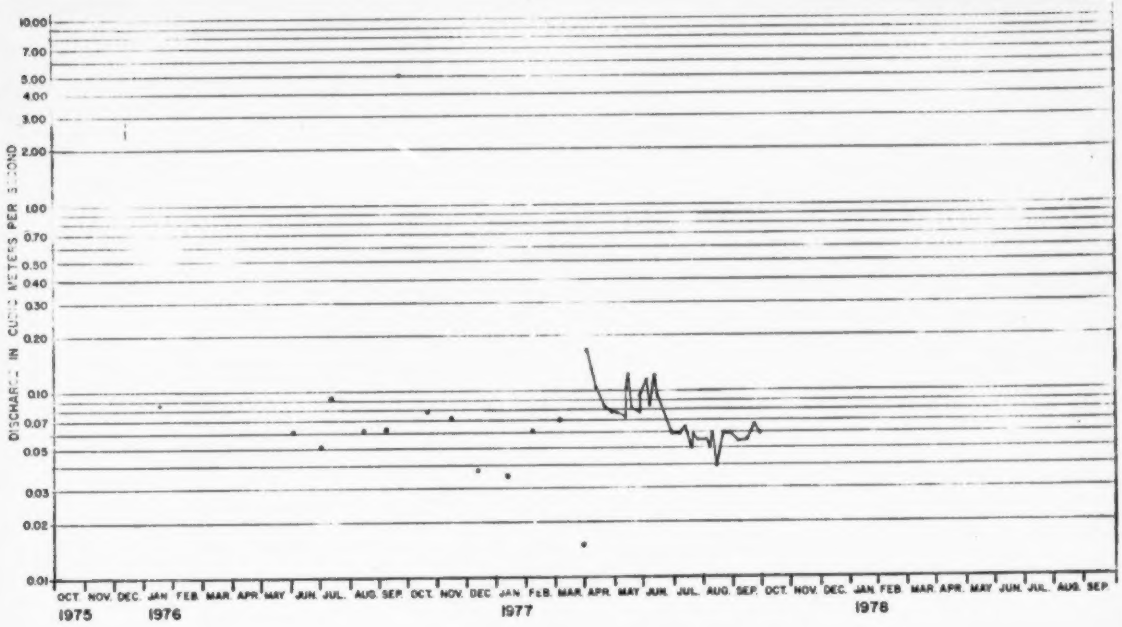


Figure 7.13 Stream discharge hydrograph for Lame Deer Creek near the mouth.

higher discharge measurement at Busby on October 31, 1977.

The data are insufficient to derive precise groundwater discharge rates above and below Busby. The three measurements above Busby are consistently higher than the reach downstream. The rate between Busby and RBC#1 appeared to be very small, and easily obscured by inherent discharge measurement error and small changes in streamflow.

A summary of the most pertinent monthly streamflow measurements taken at RBC#2 and RBC#1 is presented in Table 7.10. The measurement pairs used in

TABLE 7.10 GROUNDWATER DISCHARGE TO ROSEBUD CREEK, NORTHERN CHEYENNE RESERVATION

Measurement Date	Discharge of Rosebud Creek in Cubic Meters per Second (ft^3/sec)		Sum of Surface Tributary Discharges in Cubic Meters per Second (ft^3/sec)	Net Ground Water Discharge	
	RBC #2 near Kirby	RBC #1 Near Lame Deer		Over Entire Reach in Cubic Meters per Second (ft^3/sec)	Cubic Meters per Second per River Kilometer (ft^3/sec/r mi)
River Kilometer	288	176			
River Mile	179	110			
10/28/76	0.164 (5.79)	0.623 (22.0)	0.306 (10.8)	0.154 (5.45)	0.001 (0.08)
11/19/76	0.221 (7.82)	0.710 (25.1)	0.309 (10.9)	0.180 (6.37)	0.002 (0.09)
12/21/76	0.181 (6.40)	0.685 (24.2)	0.275 (9.7)	0.229 (8.10)	0.002 (0.12)
1/21/77	0.173 (6.11)	0.671 (23.7)	0.238 (8.4)	0.260 (9.20)	0.002 (0.13)
2/15/77	0.235 (8.3)	0.849 (30.0)	0.269 (9.5)	0.231 (8.15)	0.002 (0.12)
10/17/77	0.229 (8.10)	0.481 (17.0) from gage ht.	0.200 (7.05)	0.052 (1.84)	0.0005 (0.027)
10/27.77	0.201 (7.09	0.540 (19.1)	0.200 (7.05)	0.139 (4.96)	0.0012 (0.072)
10/31/77	0.250 (8.83)	0.524 (18.5)	0.200 (7.05)	0.074 (2.62)	0.0007 (0.038)
1/26/78	0.218 (7.72)	0.334 (19.5)	0.238 (8.4)	0.096 (3.38)	0.001 (0.05)
			Mean	0.157 (5.56)	0.001 (0.08)
			Standard Deviation	0.074 (2.61)	0.001 (0.04)

this table are from the October 1977 seepage runs and monthly current meter measurements that were not likely to be affected by irrigation, evapotranspiration, or precipitation. Surface water tributary contributions had to be estimated in several cases. The mean groundwater discharge rate between RBC#2 and RBC#1 was 0.001m^3/sec/ r km (0.08 ft^3/sec/r mi). For purposes of salt balance calculations and mining impact modeling, it is assumed that this rate is the mean annual groundwater discharge rate. The actual groundwater discharge varies along the length of the creek, as indicated in the October 1977 seepage runs, and seasonally at any location with peaks in early summer and low fall and winter.

It appears this rate could vary substantially from year to year. The rates during the fall - winter of 1976 through 1977 are consistently higher than those in the succeeding fall through winter period. Estimates of the seasonal variability of the groundwater discharge rate have not been made. Based on observations by the NCRP and others, it appears that there are much greater inflow rates following spring snowmelt and rainfall than at other times. Runoff peaks at RBC#1 from snowmelt in both 1977 and 1978 were observed to occur approximately three weeks following the peak of the melt. Because relatively little hydrologic data have been gathered on Rosebud Creek, it will take further research to better define the surface and groundwater relationships.

SURFACE WATER QUALITY

TONGUE RIVER

Basin Characteristics

The surface water quality analyses focus on the relationships between streamflow and TDS. As a generalization, the same parameters that influence streamflow characteristics influence water quality in the Tongue River. In downstream order, high quality Big Horn Mountain snowmelt, irrigation in Wyoming, the Tongue River Dam, surface and groundwater inflow, and irrigation in Montana all combine to affect water quality in the Tongue River.

Several previous investigations provide some detailed data and analyses concerning water quality in the Tongue River, but only one (NGPRP, 1974) addressed the entire basin in Montana and Wyoming. The water quality subgroup report of the Northern Great Plains Resource Program presented a brief overview of the Tongue River basin. The data presented revealed that the majority of water quality change occurs in the upper reaches of the Tongue River and Goose Creek in Wyoming. The large increase in TDS coincides with the largest irrigated areas in the drainage. Figure 7.14 depicts mean annual flows and mean (time-averaged) TDS concentrations for the period of record at most sampling stations on the Tongue River. The large increase in TDS between Dayton, Wyoming, and the state line is caused primarily by Goose Creek which has a large percent of the total irrigated area in the Tongue River basin.

The graph indicates that along with achieving maximum mean annual discharge at the state line, the Tongue River has already picked up 81 percent of the average dissolved solids concentration occurring at Miles City. About eight

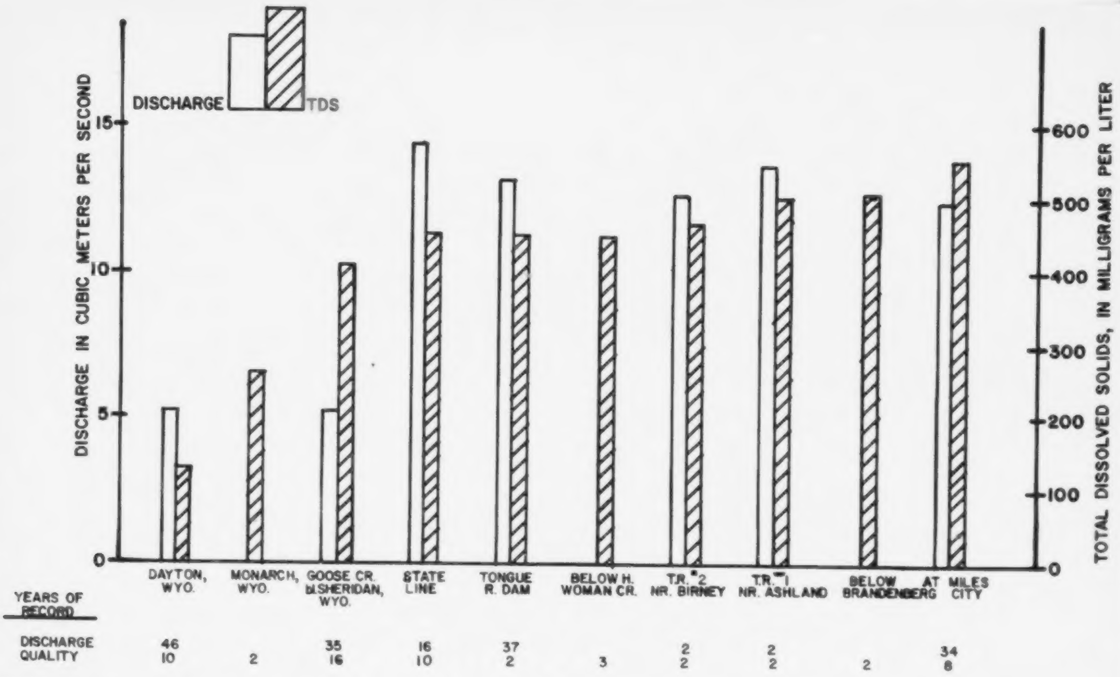


Figure 7.14. Mean annual discharge and mean total dissolved solids concentrations at various Tongue River Stations.

percent is picked up between Brandenberg and Miles City, with the remaining eleven percent contributed between the Montana State line and Brandenberg.

Knapton and McKinley (1977) presented summaries and evaluated water quality data in southeastern Montana, including the Tongue River, from the dam to Miles City. They noted that annual dissolved solids concentrations increased an average of 20 percent from the dam to the confluence with the Yellowstone River, and that changes in water type correlated well with geologic formations. The consistent chemical character of the results from sampling stations above Brandenberg was attributed to their all being underlain by the Tongue River Member of the Fort Union Formation. From near Brandenberg to the mouth, the river transects the Lebo Shale and Tullock Members. Downstream increases in sodium and sulfate were attributed to changes in lithology. They noted that water type below the dam varied seasonally, due to the release of high TDS base flow in winter and early spring, and the mixing of base flow with high quality spring run-off water for release in summer months.

The Yellowstone-Tongue Areawide Planning Organization (YTAPO) of Broadus, Montana conducted a two year investigation of water quality problems in southeastern Montana (1977). Their reports addressed agricultural impacts, particularly sediment loading from various cropping practices and locations. Return flow data were collected from several large irrigation projects, but no regional analyses were made of overall return flow discharge and quality impacts to the Tongue River. In its Water Quality Management Plan, the YTAPO reported that the largest increase in average dissolved solids and sulfates occurred between the Tongue River at Monarch, Wyoming and the state line, an increase from 273 to 469 mg/l TDS and 72 to 179 mg/l sulfate. Average suspended solids concentrations increased most between the Tongue River below Brandenberg and at Miles City, an increase from 43 to 126 mg/l.

For irrigation purposes, the salinity hazard of the Tongue River is in the medium to high class as defined by the U.S. Department of Agriculture. Medium salinity water has an electrical conductivity of 250-750 micromhos per cm. High salinity water has a conductivity of 750 - 3250 micromhos per cm. The Tongue River has been considered to have some of the best quality irrigation water in southeastern Montana. Conductivity in the Tongue River at several stations is shown in Table 7.11.

TABLE 7.11 CONDUCTIVITY FOR VARIOUS TONGUE RIVER STATIONS

	Mean	Maximum	No. of
	micromhos per cm		Samples
Near Dayton, Wyoming	240	340	118
At the State Line	704	1,370	223
Tongue River Dam	729	945	21
TR #2	697	1,000	22
TR #1	734	1,000	22
Miles City	828	1,540	304

No special irrigation practices are usually required when using medium salinity water. High salinity water cannot be used on soils with restricted drainage; salt tolerant crops should be selected. Special practices may be needed when sprinkler irrigating with high salinity water to prevent salt build-up in the surface soils.

Sodium hazard, as indicated by the sodium absorption ratio (SAR), is low for the Tongue River. An SAR of less than 10 has been classified as low sodium water by the U.S. Salinity Laboratory, and can be used generally without restriction on any soil. SAR values for various Tongue River stations are shown in Table 7.12.

Most of the suspended sediment carried by the Tongue River upstream from the dam drops out in the reservoir. A 1948 reservoir survey indicated that sediment deposition was reducing capacity by about 0.4 million m^3 (330 ac ft) annually (Dendy and Chanpion, 1973). The reservoir releases water that is almost sediment free. Knapton and McKinley (1977) noted that the Tongue

TABLE 7.12 SODIUM ABSORPTION RATIO FOR VARIOUS TONGUE RIVER STATIONS

	Mean	Maximum	No. of Samples
Near Dayton, Wyoming	0.66	0.90	166
At State Line	0.79	2.20	219
Tongue River Dam	0.78	1.10	21
TR #2	0.91	1.26	18
TR #1	1.04	1.49	18
Miles City	1.49	3.40	302

River has a high sediment carrying capacity that keeps the upstream channel flushed, as evidenced by the gravel pavement bottom present at upstream stations. Below average flows carry relatively little suspended sediment until channel sources make it more plentiful, generally downstream from the Brandenberg gaging station. Bank erosion occurs during periods of high release from the dam and in flood conditions. Localized thunder storms and snowmelt below the Tongue River Dam can cause "slugs" of sediment from ephemeral and intermittent tributary drainages to reach the river. One such occurrence on September 15, 1976 caused a suspended sediment concentratin of 848 mg/l in the storm runoff slug, while a few miles upstream concentratins dropped to 189 mg/l.

The Tongue River Along The Reservation

The Tongue River, which forms the eastern boundary of the Northern Cheyenne Reservation, derives its principal water quality characteristics from the basin features described in the previous section. NCRP water quality sampling stations in the Tongue River basin are located at stream gaging stations TR#1, TR#2, CC#1 and LC#1 (Figure 7.1). The two Tongue River station are separated by 76 river kilometers (47 river miles). Although upstream basin features dominate quality characteristics at both Tongue River stations, surface water runoff between the stations during high flow, ground water discharge at low flows, irrigation, and evapotranspiration have measureable effects on the natural river discharge - quality relationships along the Reservation.

Water type is generally a calcium-magnesium bicarbonate at both Tongue River stations. Water types for all surface water sampling stations are indicated in the tri-linear graph (Figure 7.15). Logging Creek is also a calcium-magnesium bicarbonate type, while Cook Creek is a calcium-magnesium sulfate-bicarbonate type.

Primary ionic constituents for the four Tongue River Valley sampling stations during the months of July, October, January and April are graphed

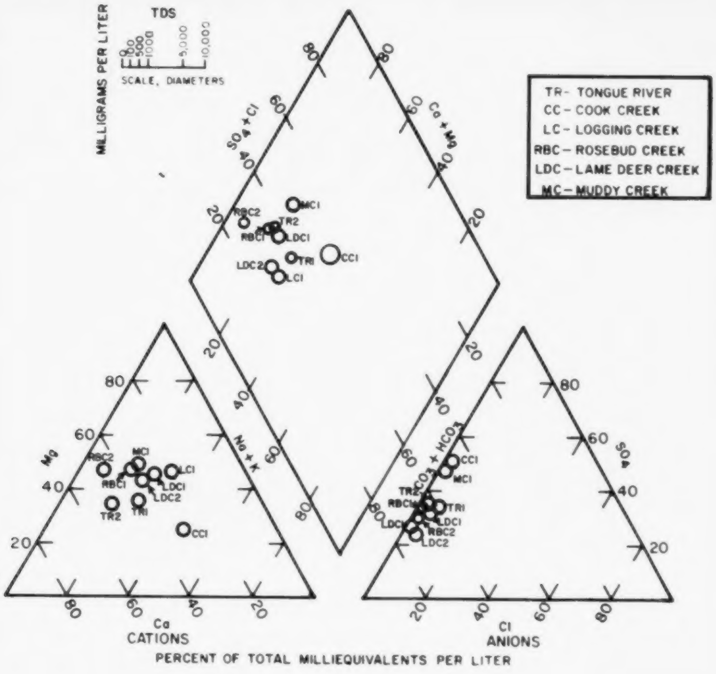


Figure 7.15. Tri-linear graph indicating water type at NCRP sampling stations.

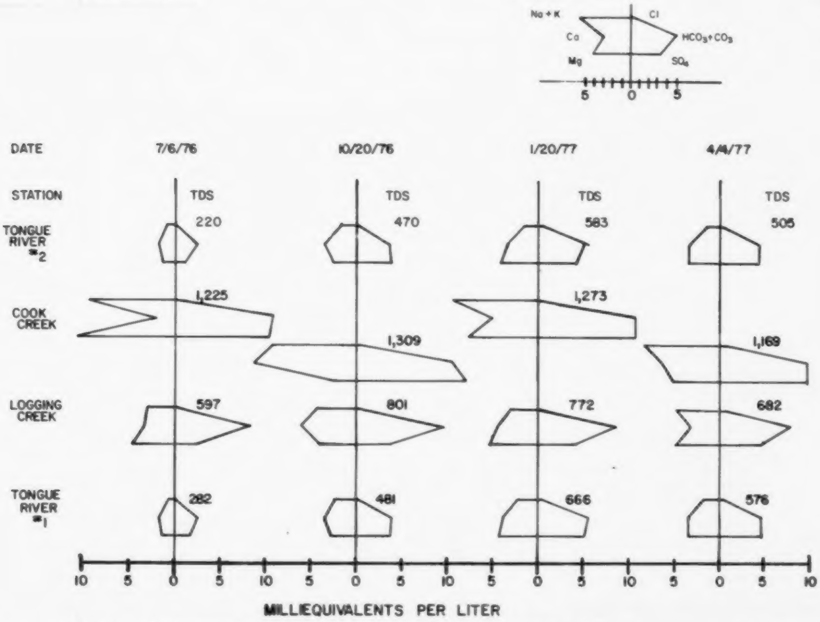


Figure 7.16 Stiff diagrams indicating the seasonal and synoptic variability of chemical constituents at Tongue River and tributary stations.

in Stiff diagrams in Figure 7.16. The results indicate several water quality trends:

a) Small tributary streams have much higher dissolved solids concentrations than the Tongue River due to geologic differences in the basins.

b) The Tongue River maintains similar water type but shows consistent, small increases in TDS between NCRP TR#2 and TR#1 on all of the sampling dates, indicating small but measureable influences of surface water and groundwater contributions and evapotranspiration.

c) Dissolved solids concentrations and water type in the Tongue River change most notably with the release of mountain snow melt water from the reservoir in mid-summer. Smaller changes occur during periods of local rainfall or snowmelt, such as on April 4,1977.

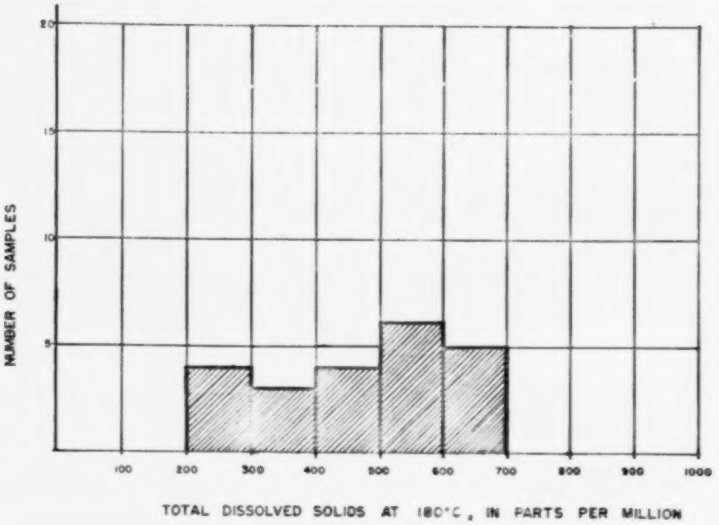
d) Cook Creek had consistently higher concentrations of sodium, sulfate, and bicarbonate than Logging Creek, indioating that the clinker deposits in the headwaters of Logging Creek play a major role in determining water quality.

Frequency distributions of total dissolved solids concentrations for stations TR#1 and TR#2 are presented in Figures 7.17a and 7.17b. It can be seen that the downstream station, TR#1, has 2 samples in the 700 to 800 ppm range while no samples were that high at TR#2. This reflects the general trend of increasing TDS in the downstream direction due to consumptive uses of irrigation, evapotranspiration due to the discharge of irrigation return flows, ground water base-flow, and surface water inflow from tributaries.

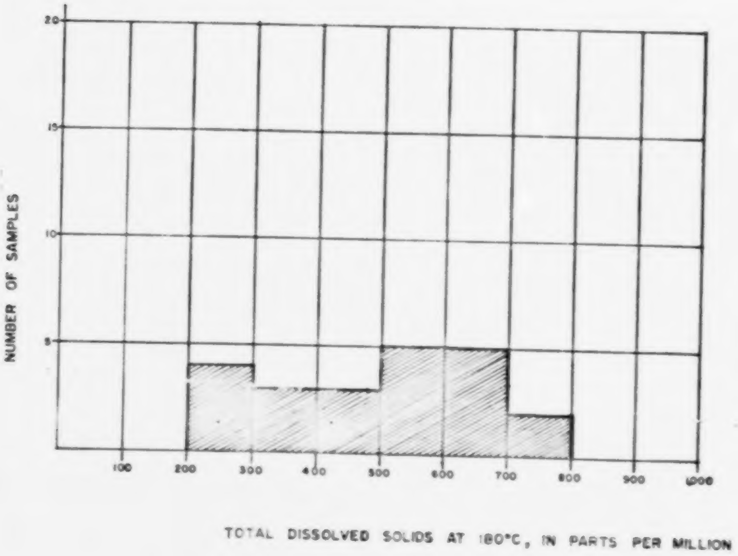
Frequency distributions for total dissolved solids sampled at Logging Creek and Cook Creek are presented in Figure 7.18. Cook Creek samples are significantly higher in TDS than Logging Creek samples. The headwaters of Cook Creek are above most of the clinker zones. Water in the sandstones and coals of this area are typically higher in TDS than in the Anderson clinker in which Logging Creek heads.

Hydrographs of total dissolved solids for stations TR#2 and TR#1 are presented in Figures 7.19a and 7.19b. The basic cyclical pattern results from storage and release of higher TDS base-flow water during fall, winter and early spring, combined with a large volume of low TDS mountain snowmelt runoff that is released in summer for irrigation uses. The downstream TR#1 TDS hydrograph is usually slightly higher than that of of TR#2 throughout the fall, winter and early spring months, due to the more pronounced effect of high TDS groundwater contributions in the stream reach during baseflow periods. During high flow periods of late spring and summer, the effect of groundwater contributions are masked during which time the TR#1 curve coincides with and some times is less than, the TR#2 TDS curve.

The highest sampled TDS concentration near TR#2 occurred during the November 1975 dam closure and was 430 mg/l greater than the 2 year mean. The lowest TDS concentration occurred in May 1977, following the annual hydrograph peak and was 260 mg/l less than the 2 year mean. The highest TDS



(a)



(b)

Figure 7.17. Frequency distributions of total dissolved solids samples at TR #2 (a) and TR # 1 (b).

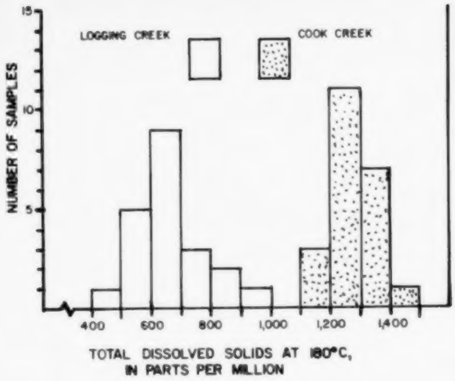


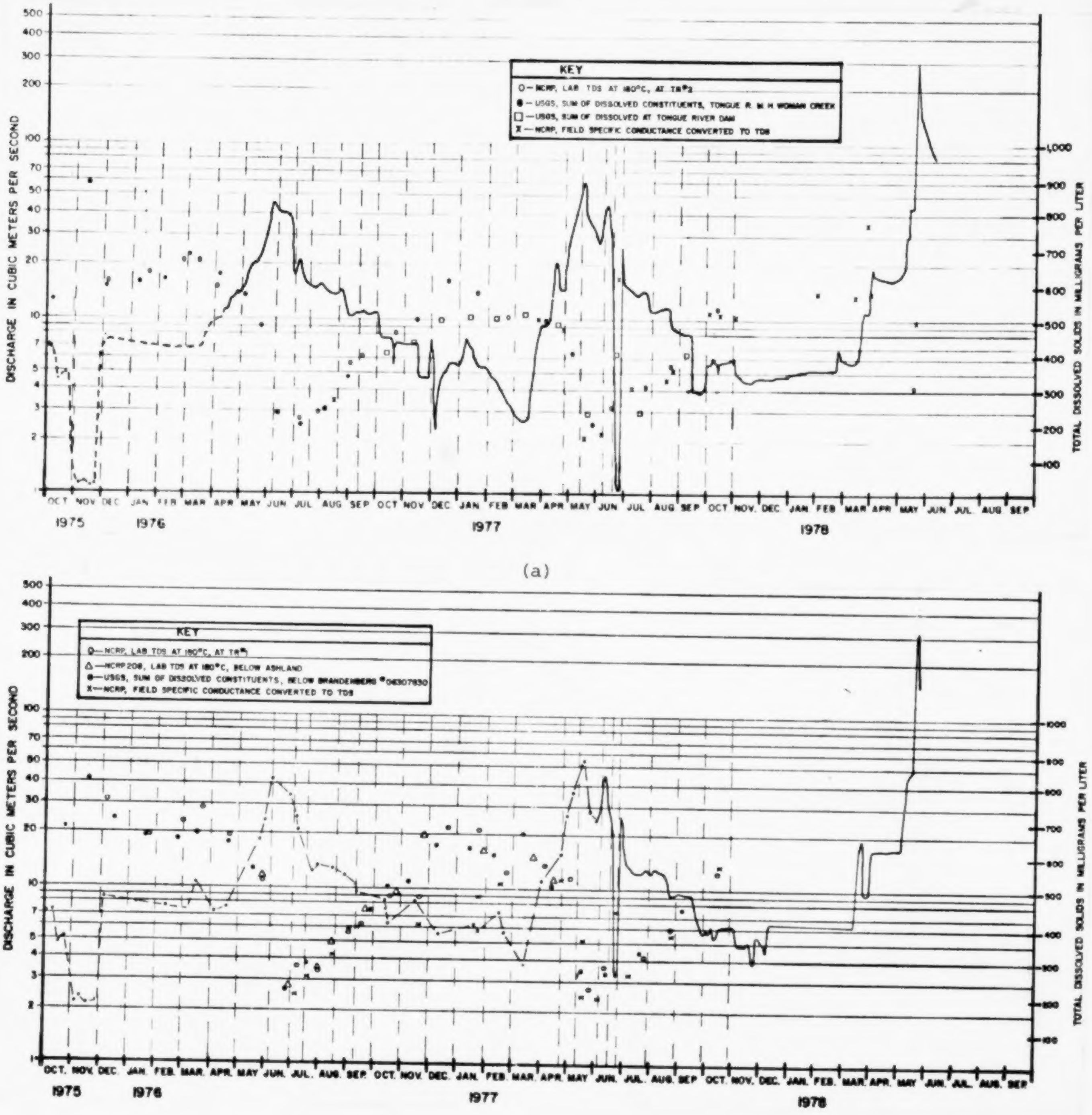
Figure 7.18 Frequency distributions of total dissolved solids samples at Logging Creek #1 and Cook Creek #1.

concentration sampled at TR#1 occurred also during November 1975, and was about 300 mg/l above the 2 year mean. The lowest TDS level occurred in May 1977, and was 270 mg/l less than the 2 year mean.

The hydrographs at TR#2 and TR#1 are almost identical during high flows in the spring and summer. TDS concentration differences are at a maximum during during fall and winter when concentrations are 25 to 100 mg/l greater at TR#1 than at TR#2.

The average dissolved solids concentrations in the Tongue River and tributaries can be expressed as either a time-weighted average or a discharge-weighted average. Time-weighted averages are useful for assessing the quality of water available in the river during normal discharge periods. The discharge-weighted average gives emphasis to the quality of water during periods of high flow. Instead of each water sample representing a certain time period, it is assumed to represent part of the total volume of water passing the sampling station during the period of the average. The discharge-weighted average is useful in geochemical studies, because it is mathematically compatible with the mean river discharge, and can be used to calculate the total quantities of dissolved solids transported by the stream during a year or any other selected time period. Both time-weighted and discharge-weighted averages for Tongue River stations are presented in Table 7.13.

The water sampling results used to calculate the time-based averages are indicated on the hydrographs of Figure 7.19 for points labled as NCRP stations, Lab TDS at 180°C. Discharge-weighted averages were calculated by averaging NCRP data for TR#2 with USGS station data for Tongue River below Hanging Woman Creek in the case of TR#2, and averaging NCRP 208 data downstream form Ashland, Montana with data from TR#1. USGS station data for Tongue River Dam, and below Brandenberg, as well as NCRP field specific conductance measurements are shown for comparison purposes only, and were not used to



(a)

(b)

Figure 7.19. Total dissolved solids and discharge hydrographs for stations TR #2 (a) and TR #1 (b).

TABLE 7.13. TIME AND DISCHARGE AVERAGED TDS CONCENTRATIONS

Time-Averaged TDS Concentrations For Samples Taken

December, 1975 through October, 1977

STATION	Mean	Maximum	Minimum	Standard Deviation	No. of Samples
		Milligrams per liter			
TR #2	465	674	204	149	22
TR #1	503	754	264	166	22
Cook Creek	1,270	1,406	1,166	65	23
Logging Cr.	677	911	454	102	21

Discharge-Averaged TDS Concentrations for Samples Taken

December, 1975 through October, 1977

STATION	Mean	Maximum Dissolved Load Sampled	Minimum Dissolved Load Sampled	Mean Dissolved Load
	mg/l	Tons/day	Tons/day	Tons/day
TR #2	397	1,046 (5/27/76)	226 (11/18/76)	512
TR #1	424	1,301 (5/2/77)	291 (10/20/76)	592

calculate average TDS concentrations. The vertical dashed lines on the TDS hydrograph indicate the discharge volumes used to weight the TDS values in obtaining the discharge-weighted mean.

Maximum salt loads occur usually in spring when releases from the Tongue River Dam increase, and the water is primarily winter baseflow that has not been mixed with mountain snowmelt water. Following the peak discharge, TDS drops rapidly as lower TDS runoff water mixes and is released from the reservoir. Minimum dissolved solids loads occur generally in the fall when discharge is low. The mean daily dissolved solids load increased by 80 tons between TR#2 and TR#1.

The final discussion of stream discharge-water quality relationships explores the capability to predict stream water quality. As pointed out by Hem (1970), the goal would be to develop a dissolved solids rating curve at a stream-measuring station, correlating water discharge with TDS. An ideal relation would be an inverse function with a slope of minus one. In the Tongue River, this relation is highly modified by the reservoir and runoff processes which induce a strong hysteresis into the curve. Figure 7.20 is a graph of discharge versus TDS at TR#2 for 23 monthly samples. A general elongated clock-wise loop makes it possible to identify a 100-200 milligram per liter range of concentration at any given discharge and time of year. Figure 7.20 illustrates the complex nature of the stream discharge-water quality relationships in the Tongue River. A much better TDS relation exists between TR#2 and TR#1 at any single point in time throughout the year.

ROSEBUD CREEK

Basin Characteristics

Collection of water quality data on Rosebud Creek began in 1973. The USGS began collecting monthly water quality samples at four locatins in October 1974 (Figure 7.1). The Montana Water Quality Bureau conducted several synoptic sampling runs at six sites from the headwaters to the mouth in 1973 and 1974. The Water Quality Bureau, in its Water Quality Inventory and Management Plan for the Middle Yellowstone Basin (Karp and Botz, 1975), was first to note some water quality trends of Rosebud Creek.

They observed a general downstream increase in specific conductance, particularly between Kirby and Busby, and suspected that groundwater discharge in this reach may be a major cause. Sodium, magnesium, sulfate and chloride all increased somewhat in this reach. Karp and Botz noted that contrary to most surface waters, Rosebud Creek exhibited a higher milliequivalence per liter of magnesium than of calcium. This was also true of most tributaries to Rosebud Creek that were sampled. A definite increase in suspended sediment concentrations from upper to lower stations was noted.

Knapton and McKinley (1977), using USGS station data for water year 1975, analyzed physical and chemical data at four sampling sites on Rosebud Creek

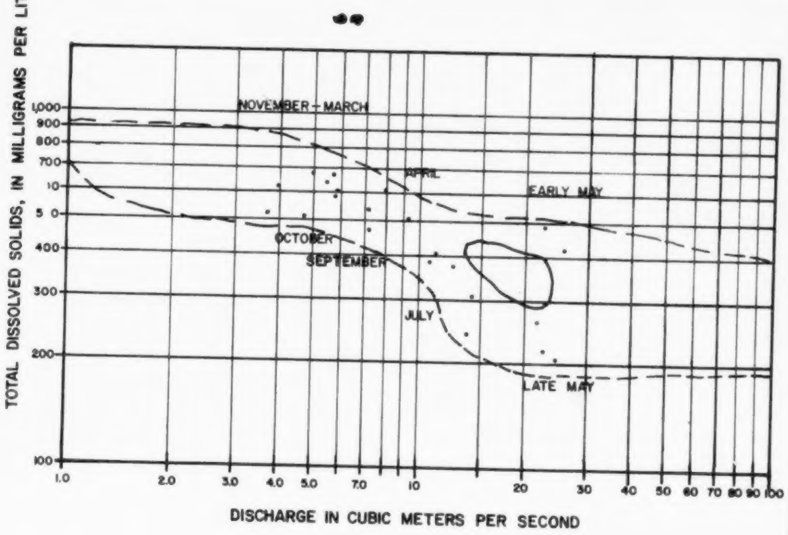
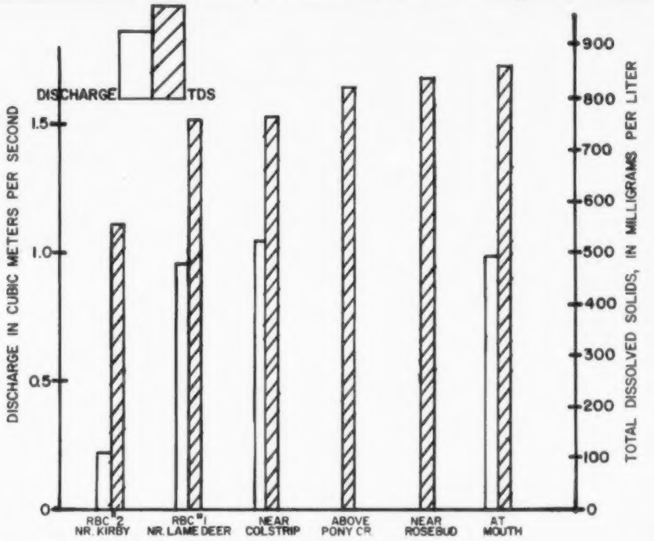


Figure 7.20. Stream discharge versus total dissolved solids for 23 monthly samples at TR #2.

from near Colstrip to the mouth. They found only slight differences in chemical quality of the water from the upstream station near Colstrip, through the second and third stations during the medium and low flows. Somewhat larger chemical changes were observed between the stations south of Rosebud and at the mouth. Total dissolved solids increased slightly between the first and second stations and between the third and fourth stations. The authors attributed the variations in streamflow, water types and dissolved solids concentrations to basin geology and said, in part, that this could be correlated with geologic formations. The greatest change in water type occurred where the channel intersects the Hell Creek Formation, between the two downstream stations. Suspended sediment generally increased slightly moving downstream, but concentrations increased sharply between the third station and the mouth.

Trends in average streamflow and TDS from near Kirby, Montana, to the mouth are indicated in Figure 7.21, compositing USGS and NCRP data. The graph is based on 12 months of data corresponding to a concurrent period of record at RBC#1, RBC#2, and the USGS station near Colstrip. The graph indicates that most of the discharge and TDS concentration at the mouth is already present at NCRP station RBC#1 north of Lame Deer. On an annual basis, Rosebud Creek loses discharge and gains TDS in the downstream direction throughout its lower half. This is probably due partially to consumptive losses to evapotranspiration, and as suggested by Knapton and McKinley (1977), partially to subsurface seepage losses. In the upstream half, however, average discharge more than doubles in the reach between RBC#2 and RBC#1. Total dissolved solids concentrations increase significantly due to the inflow of both surface tributaries and groundwater that are higher in TDS than the water at RBC#2.



YEARS OF RECORD						
DISCHARGE	2	2	5/76-4/77			5/76-77
QUALITY	2	2	3	3	3	3

Figure 7.21. Mean discharge and mean total dissolved solids concentrations at various Rosebud Creek stations.

For irrigation purposes, the salinity hazard of Rosebud Creek is in the medium to high categories, as defined by the U.S. Department of Agriculture. Conductivity in Rosebud Creek at several stations is shown in Table 7.14. Generally salinity has not been reported to be a major problem with Rosebud Creek water using flooding-type irrigation systems. Special consideration may have to be given to using Rosebud Creek for sprinkler irrigation since electrical conductivity is generally greater than 750 micromho's. Sodium hazard, as indicated by SAR, is quite low for Rosebud Creek. SAR values for various Rosebud Creek stations are shown in Table 7.15.

Rosebud Creek and Tributaries on the Reservation

Unlike the Tongue River, substantial changes in the water quality of Rosebud Creek occur within the Reservation. The previous regional discussion of Rosebud Creek water quality data indicated that average stream discharge more than doubled, and average TDS concentrations increased by about 37 per cent, between RBC#2 and RBC#1. The water type, chemical constituents, frequency characteristics, and relation of discharge to water quality of Rosebud Creek and tributaries on the Reservation are important parameters in defining the

TABLE 7.14. CONDUCTIVITY AT VARIOUS ROSEBUD CREEK STATIONS

	Mean	Maximum	No. of Samples
	micromho's per cm		
RBC #2, near Kirby	841	1,000	24
Rosebud Creek near Colstrip	1,181	1,750	33
Rosebud Creek at Mouth	1,310	2,060	34

TABLE 7.15. SAR VALUES FOR ROSEBUD CREEK STATIONS

	Mean	Maximum	No. of Samples
RBC #2, near Kirby	0.46	0.81	18
Rosebud Creek near Colstrip	1.19	1.70	33
Rosebud Creek at Mouth	1.84	3.80	34

existing hydrologic water quality system.

Water is a calcium-magnesium bicarbonate type at both Rosebud Creek sampling stations (Figure 7.15). The percent of total milliequivalents per liter of magnesium remained about the same while the percent of calcium decreased from about 45 percent to 35 percent between RBC#2 and RBC#1. The percent of total milliequivalents per liter of sodium increased from less than 10 percent at RBC#2 to about 20 percent at RBC#1. An approximate 5 percent increase in sulfate concentrations occurred between the upstream and downstream Rosebud Creek stations. This supports hydrologic observations that increased discharge within the Reservation comes from groundwater and tributary baseflow typically higher in sodium and sulfate. Muddy Creek is a magnesium-calcium sulfate-bicarbonate type. Along with Cook Creek, Muddy Creek exhibited a high sulfate level of about 50 percent of the total milliequivalents per liter.

Lame Deer Creek near its mouth is a calcium-magnesium bicarbonate type. Sulfate and chloride concentrations increased almost 10 percent between a sampling station five miles upstream from Lame Deer and the station near the mouth. This is at least partially attributed to the sewage lagoon discharge at Lame Deer.

Primary ionic constituents during four selected time periods are graphed in Stiff diagrams in Figure 7.22. Frequency distributions of TDS for Lame Deer Creek, Muddy Creek, and Rosebud Creek are presented 7.23, 7.24a, and 7.24b. Analyses of the results indicate a number of water quality characteristics:

a) Total dissolved solids, particularly sodium and sulfate, increased markedly between RBC#2 and RBC#1 during all four sampling periods in Figure 7.22. These ions indicate the influence of groundwater discharge either directly to Rosebud Creek channel or via springs and baseflow from major tributaries.

b) total dissolved solid concentrations at RBC#2 are substantially lower and much less variable for the 23 monthly sampling periods. Both of these factors are the result of the dominance of clinker-fed baseflow in comprising most of the discharge at RBC#2. In all clinker aquifer units sampled on the Reservation, waters were relatively low in TDS.

c) total dissolved solid concentrations at RBC#1 are substantially higher than at RBC#2. This is primarily due to the inflow of both surface tributary and groundwater containing higher TDS than at RBC#2. Evaporation and transpiration play additional roles in concentrating dissolved solids, although they are probably of lesser importance because TDS increases between RBC#2 and RBC#1 are average or greater than average in winter months when there is no evapotranspiration.

d) Generally, water type at RBC#2 and RBC#1 varied most in response to snowmelt runoff in the April 1977 sampling period.

e) Although Lame Deer Creek and Muddy Creek drain the same stratigraphic units of the Tongue River Member and are similar in basin area, their waters differ significantly in ionic makeup and TDS. The TDS at the mouth of Muddy Creek almost always averages over 200 mg/l higher than TDS at the mouth of Lame Deer Creek and often averages over 400 mg/l higher than the upstream Lame Deer Creek station. Lame Deer Creek water quality is primarily influenced by lower TDS waters from the Anderson Unit clinker, where most of the flow originates. The headwaters of Muddy Creek lie above the Anderson seam which is thinner and contains little clinker in this area. The aquifer units contributing to Muddy Creek contain a mixture of coal, sandstone and clinker materials. Both factors result in the higher TDS waters characteristic of Muddy Creek.

Hydrographs of TDS for stations RBC#2 are presented in Figures 7.25a and 7.25b. The RBC#2 sampling station near Kirby showed notably little correlation between discharge and TDS concentrations. Only following a rapid snowmelt in April 1977 did the sampled TDS concentration drop more than 100 mg/l below

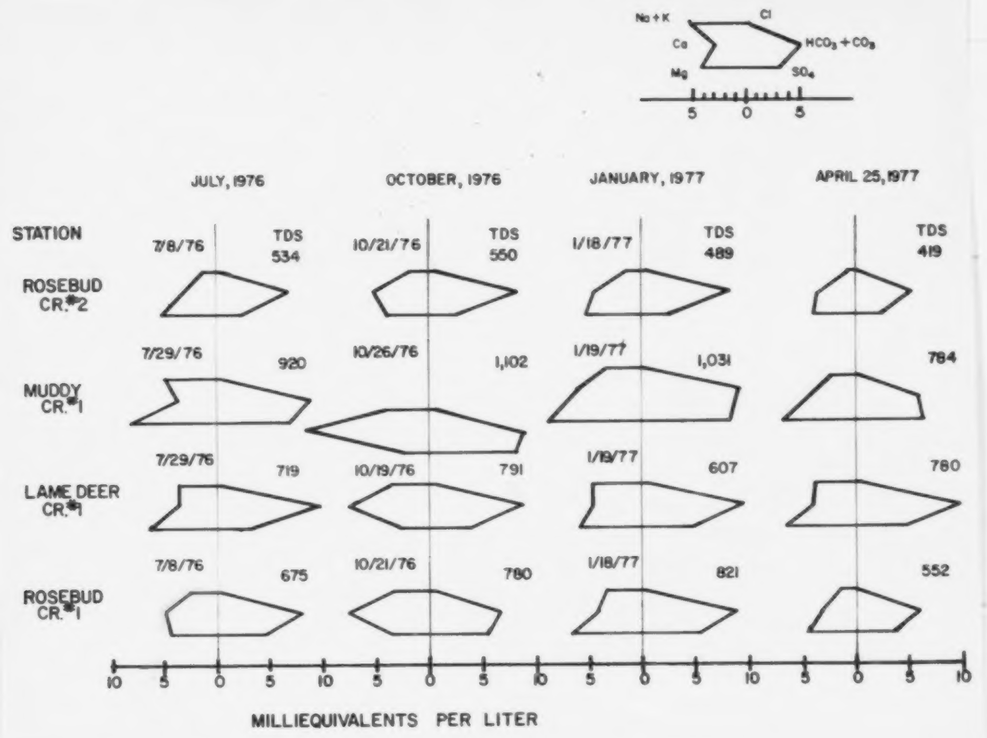


Figure 7.22 Stiff diagrams indicating the seasonal and synoptic variability of chemical constitutents at Rosebud Creek and tributary stations.

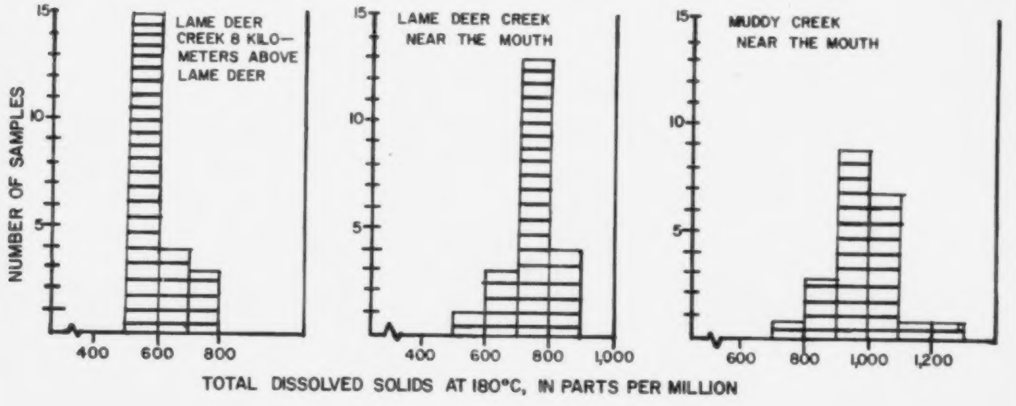


Figure 7.23 Frequency distributions of total dissolved solids samples at Lame Deer Creek #1 and #2 and Muddy Creek #1.

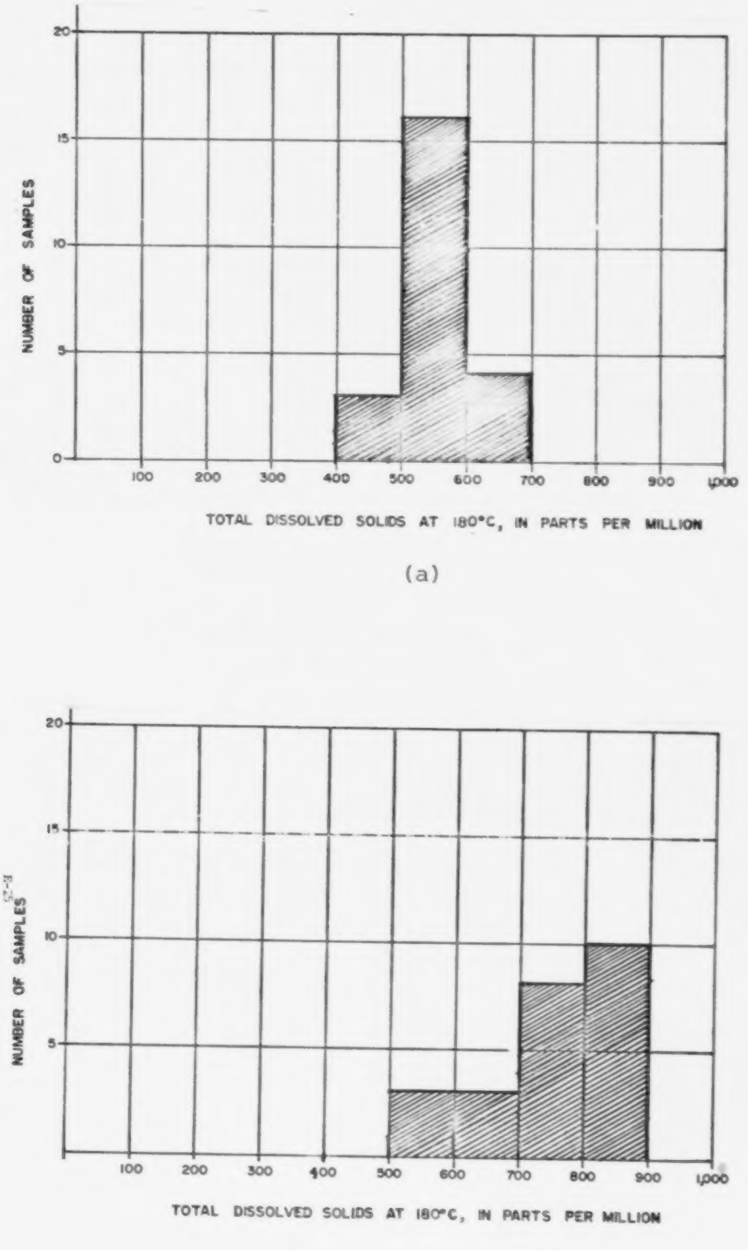


Figure 7.24. Frequency distributions of total dissolved solids samples at RBC #2 (a) and RBC #1 (b).

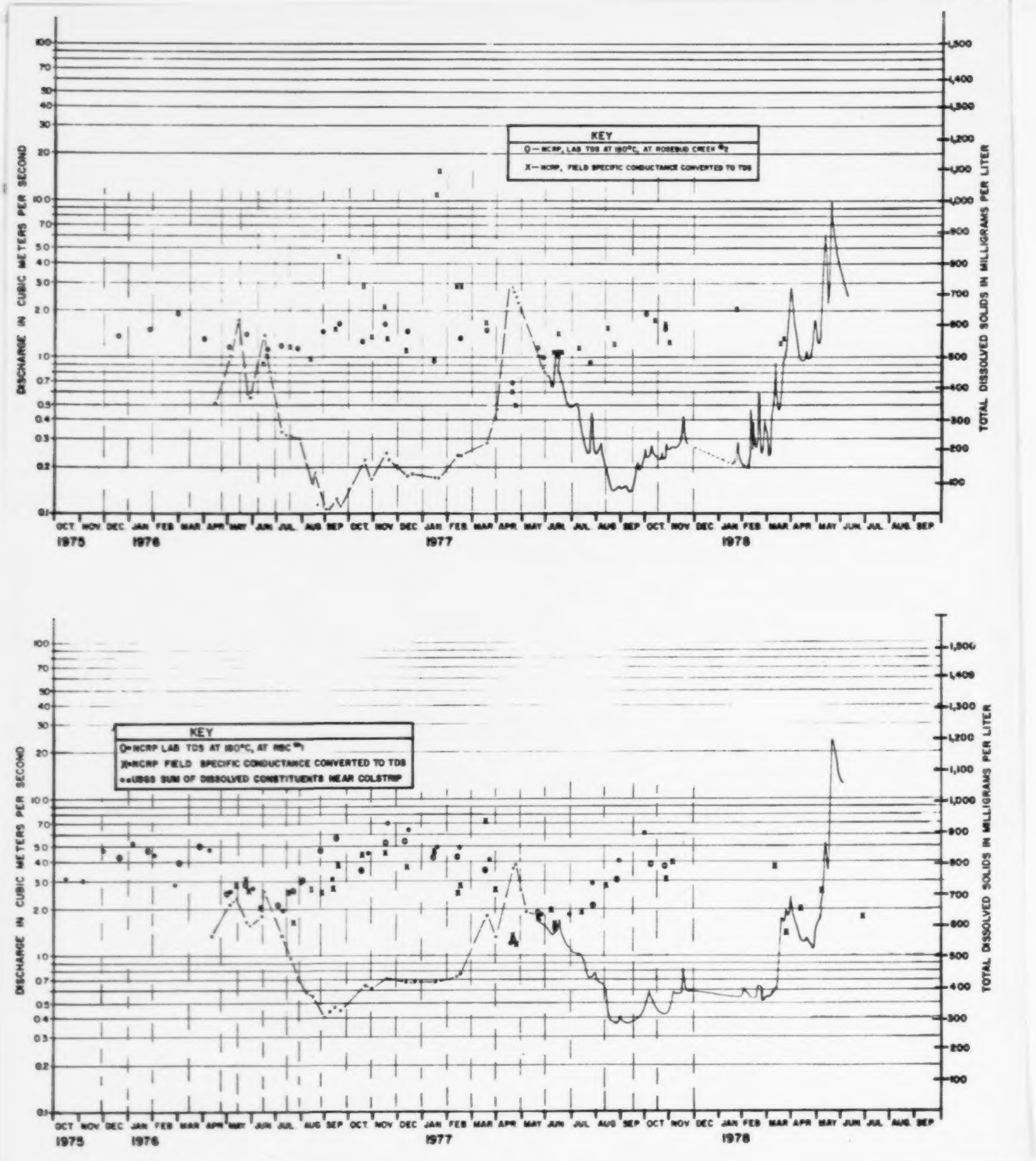


Figure 7.25. Total dissolved solids and discharge hydrographs for stations RBC #2 (a) and RBC #1 (b).

the 23 sample average. The highest TDS level sampled during winter baseflow period was only 81 mg/1 above the two year average. The dominance of baseflow from clinker aquifers is the principal reason for this water quality consistency.

The downstream station RBC#1 shows a more cyclical pattern of TDS decreasing during spring snowmelt and early summer rainfall, moderate to sharp increases in TDS as discharge decreases throughout the summer months followed by a plateau of high TDS baseflow during winter months. The sampled minimum concentration occurred during the April 1977 snowmelt and was just over 200 mg/l below the two-year mean. The sampled maximum TDS concentration occurred during a September 1976 baseflow period and was 125 mg/l greater than the two year mean.

Comparing the TDS concentrations at RBC#1 and RBC#2, at any single point in time, they approach their minimum difference of about 100 mg/l during May and June when rainstorm runoff and discharge from recently recharged alluvial valley aquifers dilutes salt concentrations at RBC#1. TDS concentration differences are at their maximum during fall and winter baseflow periods when they can exceed 300 mg/l.

Average dissolved solids concentratins in Rosebud Creek can be expressed as either a time-weighted average or a discharge-weighted average, as discussed previously concerning the Tongue River. In the case of Rosebud Creek, however, the time-based and discharge-based TDS averages do not vary greatly because there is less overall variability in water quality. Standard deviations of TDS sample means for Rosebud Creek are 50 for RBC#2, 99 for RBC#1, while they are 149 for TR#2 and 166 for TR#1. Both time-weighted and discharge-weighted averages of TDS for Rosebud Creek stations are presented in Table 7.16.

The relationship between stream discharge and TDS in Rosebud Creek is even less definitive than that for the Tongue River. A graph of discharge versus TDS at RBC#1 for 20 monthly samples is presented in Figure 7.26. The numbers by each point correspond to the month of the year. For any given discharge, TDS varies over a range of 200 mg/l. Correlation by month was better, with any given month having a TDS range of 100 mg/l. A discharge - TDS graph of station RBC#2 would show less of a slope than RBC#1, because as indicated in TDS hydrograph of Figure 7.23a, TDS varies only slightly over the period of record.

SALT BALANCE CALCULATIONS

Water and salt balance calculations for the Tongue River and Rosebud Creek were used to check the consistency of NCRP streamflow, groundwater and water quality data. Discharge and salt balance equations were analyzed in an attempt to account for the principal inputs and losses of streamflow and salt load as measured by NCRP field data, and to check a calculated downstream output with the measured output.

The salt balance presented here is based on limited amounts of water

TABLE 7.16. TIME WEIGHTED AND DISCHARGE AVERAGED TDS CONCENTRATIONS FOR TONGUE RIVER

Time-Averaged Total Dissolved Solids Concentrations for samples taken December, 1975 through October, 1977.

Station	Mean	Maximum	Minimum	Standard Deviation	No. of Samples
	Milligrams per liter				
RBC #2	555	636	419	50	23
RBC #1	758	883	552	99	23
Muddy Cr.	978	1,235	784	100	22
L.D. Cr. above L.D.	614	791	539	69	22
L.D. CR. near mouth	740	888	602	83	22

Discharge-Averaged Total Dissolved Solids Concentrations for samples taken December, 1975 through October, 1977.

Station	Mean	Maximum load sampled	Minimum load sampled	Mean Salt load
	mg/1	tons/day	tons/day	tons/day
RBC #2	535	106 (4/25/77)	5,8 (9/2/76)	24.1
RBC #1	741	194 (4/25/77)	33.0 (9/1/76)	77.3

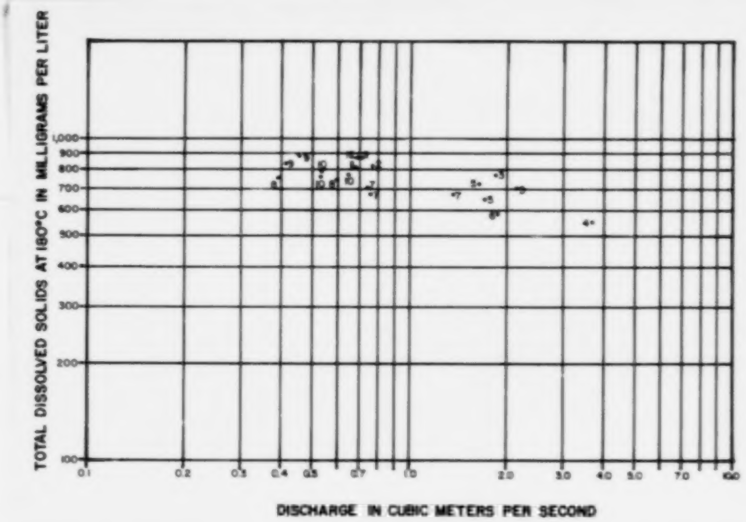


Figure 7.26 Stream discharge versus total dissolved solids for 20 monthly samples at RBC #1.

quality data and is intended more to provide a check on the consistency of the data rather than fully characterize the solute transport in Tongue River and Rosebud Creek. Most quantitative chemical balance studies of natural streams utilize one per day or daily composited water samples or a continuous record indicating water quality such as electrical conductivity. Daily sampling was not possible in this investigation, however. It was felt that gross estimates of the salt balance in the two drainages were valuable in aiding the description of the natural hydrologic systems on the Reservation and laying the basis for assessing mining impacts. A schematic diagram of the inputs and outputs of the hydrologic balance model is presented in Figure 7.27.

The first step in balancing the hydrologic system is to balance all inputs and outputs of stream discharge. The basic equation is:

$$Q_1 = Q_2 + Q_{gw} + Q_{sw} - Q_{id} + Q_{rf} - Q_{et},$$

where:

Q_1 = The discharge at the downstream measuring station (TR #1 or RBC#1),

Q_2 = The discharge at the upstream measuring station (TR#2 or RBC#2),

Q_{gw} = The amount of groundwater discharge between Q_1 and Q_2,

Q_{sw} = The surface water tributary discharge between Q_1 and Q_2,

Q_{id} = The amount of irrigation diversions between Q_1 and Q_2,

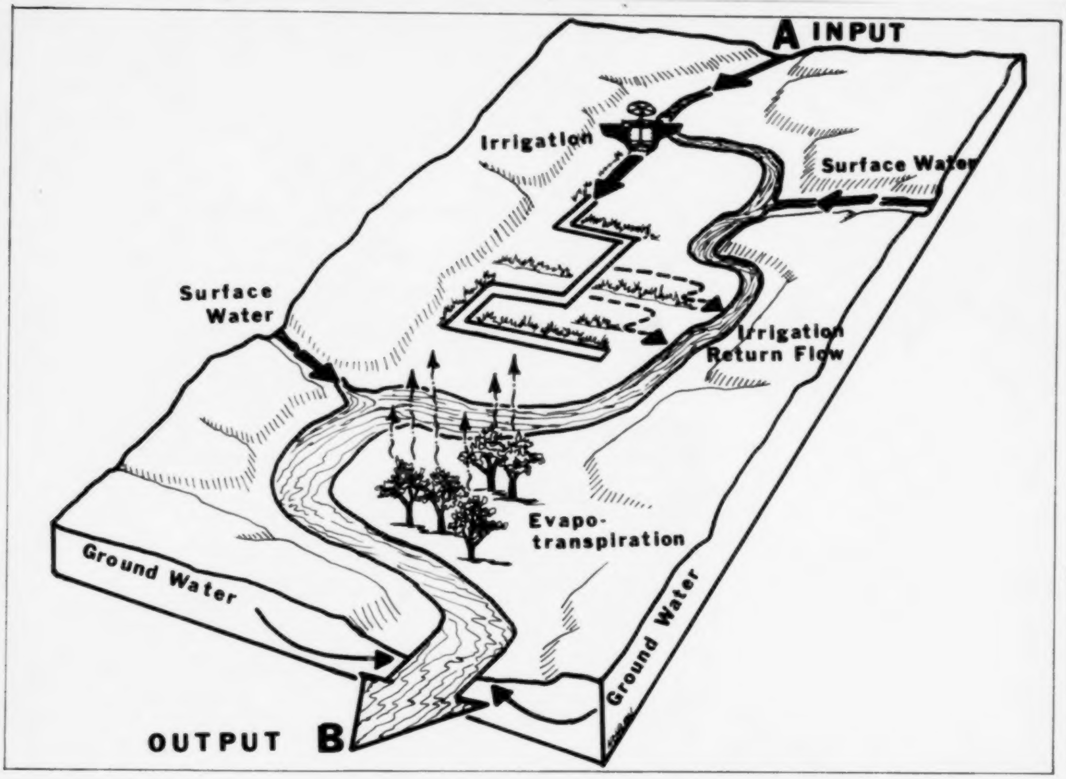

A INPUT
Irrigation
Surface Water
Surface Water
Irrigation Return Flow
Evapo-transpiration
Ground Water
Ground Water
OUTPUT B

Figure 7.27. Schematic diagram depicting principal inputs and outputs of the hydrologic balance.

Q_{rf} = The amount of irrigation return flow between Q_1 and Q_2,

Q_{ET} = The amount of water lost to evaporation and transpiration between Q_1 and Q_2.

The discharge at the upstream and downstream gaging stations on Tongue River and Rosebud Creek is the mean flow during the period of water quality data collection, December 1975 through October 1977. For periods when continuous streamflow records were not available, estimates were made based on monthly discharge measurements, and correlations with other nearby gaging stations.

The amount of groundwater discharge to the stream was calculated from the mean groundwater discharge rate along the Reservation as determined from seepage data. It was assumed that the mean rate based on fall and winter seepage run data was representative of the mean rate during water years 1976 to 1977.

Surface water tributary discharge to Tongue River was based partially on continuous record data for Otter Creek, Cook Creek, and Logging Creek, and partially on monthly discharge measurements and correlations with nearby gaging stations. Runoff from the ungaged watershed area between TR#2 and TR#1 was estimated using a runoff/area coefficient, developed from Cook Creek and Logging Creek records. Surface tributary discharge to Rosebud Creek was calculated as the sum of the mean discharge charges of Lame Deer Creek, Muddy Creek, Davis Creek, Thompson Creek, and Corral Creek, during the 1976 and 1977 water years. Flow data were developed from continuous records, monthly discharge measurements and correlations with nearby gaging stations.

The irrigation diversions and return flow rates were developed from NOAA meterological data, average crop use estimates, and irrigation efficiency estimates. The amount of irrigated acreage along the Tongue River was mapped and calculated from aerial photographs by NCRP. Estimates of evaporation rates were developed from NCRP Class A pan data for Lame Deer and Tipi Ranch. Evaporation amounts were based on NCRP gaging station data for mean channel geometry and travel times. It was assumed that free-water evaporation rates occurred over the mean channel width. An additional amount of water was lost by transpiration from riparian vegetation. This was ignored over the 1976 and 1977 water year periods. All irrigation diversion, return flow, and evaporation rates are given as annual averages.

The hydrologic balance equations for Tongue River and Rosebud Creek are presented in Table 7.17. The downstream discharge at TR#1 and RBC#1 is shown, both as calculated from the equation, and as actually measured. The calculated downstream discharge at TR#1 is 0.7 percent less than the measured value. The calculated discharge at RBC#1 is 9.2 percent less than the measured discharge.

The principal reason for the slightly lower calculated discharge at TR#1 is most likely due to underestimation of the mean groundwater discharge rate. Rates based on fall and winter seepage runs do not include the higher discharge peaks that occur after snowmelt and early summer rains. The same reason partially accounts for the lower calculated discharge amount at RBC#1.

Groundwater discharge to Rosebud Creek in the Reservation amounts to 13 percent of the mean flow at RBC#1. Groundwater discharge to Tongue River along the Reservation constitutes only five percent of the mean flow at TR#1. Another reason for the lower calculated discharge at RBC#1 may be surface tributary runoff from ungaged drainages. The surface tributary contribution shown in Table 7.15 includes that of all principal drainages. However, numerous other small drainages occasionally discharge storm runoff or snowmelt water to Rosebud Creek. Existing hydrologic data did not allow an estimate to be made of this additional runoff amount. The difference between calculated and measured downstream discharge at TR#1 and RBC#1 was distributed evenly between the groundwater and surface tributary components to balance the hydrologic system before performing the salt balance.

The salt concentration at the downstream measuring stations are dependent on the concentration and discharge of each input and output in the hydrologic balance. The salt balance equation is:

$$C_1Q_1=C_2Q_2+C_{gw}Q_{gw}+C_{sw}Q_{sw}-C_{id}Q_{id}+C_{rf}Q_{rf}-C_{et}Q_{et},$$

with "C" representing the discharge-weighted concentration of total dissolved solids in milligrams per liter for each of the inputs and outputs in the basic hydrologic balance equation.

The reactions of water with mineral solids in the streambed and in suspension, reactions among solutes in the stream, and uptake of minerals and nutrients by biological organisms occur and influence the salt balances. Quantification of these processes was beyond the scope of this project. The effect of these processes is likely small.

The salt concentration at TR#2 is the discharge-weighted mean presented in Table 7.13. The concentration of TDS in the Tongue River groundwater component is the mean of one to nine samples from each of 13 wells located in the alluvium of the Tongue River Valley along the Reservation. The surface water tributary TDS component was calculated by discharge-weighting the mean TDS of runoff from the ungaged watershed area by 300 mg/l. The TDS of the irrigation diversions was assumed to be the average of the mean TDS concentrations at TR#2 and TR#1. The TDS concentration of the irrigation return flows was the mean of 45 return flow samples taken by the Yellowstone-Tongue Water Quality Project (YTAPO , 1978) on the lower Tongue River and Yellowstone River near Miles City and Forsyth, Montana. It was assumed that evaporation removed water, but not salt, from the stream.

The salt concentration at RBC#2 is the discharge-weighted mean presented in Table 7.16. The TDS concentration of the Rosebud Creek groundwater component is the mean of 14 samples from two NCRP wells and one-time samples from 12 domestic wells all finished in Rosebud Creek alluvium. The surface water tributary TDS component was calculated by weighing the time-averaged TDS values for each of the six principal tributary streams by the mean discharge. Stream diversions for irrigation are few and they were ignored in the salt balance.

The salt balance equations for Tongue River and Rosebud Creek are presented in Table 7.18. The downstream TDS concentration at TR#1 and RBC#1 is shown both as calculated from the equation and as actually measured. The calculated TDS at TR#1 is nine percent higher than the measured value, and the calculated TDS at RBC#1 is two percent lower than the measured value.

There are several reasons that one or more of the calculated TDS exceeded the measured TDS at TR#1 . It is possible that one or more of the TDS inputs may be higher than actual. The groundwater component may not have a relatively constant TDS concentration as assumed. Recharge water entering the system in spring and early summer may reach the Tongue River in a shorter time, due to higher gradients, and pick up less soluable salts than at other times. Results of the quarterly ground water sampling schedule did not indicate a trend for reduced TDS levels in spring and early summer; however, the sampling frequency may not have been great enough to characterize the groundwater hydrograph peak. Another reason may also be attributed to the shorter period of continuous streamflow record available at TR#1, which could affect the

TABLE 7.17. HYDROLOGIC BALANCE OF TONGUE RIVER AND ROSEBUD CREEK

MEAN DISCHARGE IN CUBIC METERS PER SECOND
(and cubic feet per second)

TR #2	Groundwater	Surface Tribs.	Irrig. Diver.	Irrig. Ret. Flow	Evaporation	TR #1	
						Calculated	Measured
13.53 (478)	0.798 (28.2)	0.402 (14.2)	0.213 (7.53)	0.118 (4.17)	0.071 (2.51)	14.56 (514)	14.66 (518)
RBC #2						RBC #1	
						Calculated	Measured
0.437 (16.7)	0.137 (4.84)	0.414 (14.6)	0	0	0.033 (1.17)	0.990 (35.0)	1.09 (38.7)

TABLE 7.18. SALT BALANCE FOR TONGUE RIVER AND ROSEBUD CREEK

Concentration (C) of Total Dissolved Solids in Milligrams per Liter, Water Discharge (Q) in Cubic Meters per second and Product (P)

TR #2			Groundwater			Surface Trib.			Irrig. Diver.			Irrig. Det. Fl			Evapora.			TR #1			TR #1
C	Q	P	C	Q	P	C	Q	P	C	Q	P	C	Q	P	C	Q	P	C	Q	P	C. Measure
397	13.53	5,371	1,147	0.848	973	924	0.452	418	411	0.213	87.5	596	0.118	70.3	0	0.071	0	460	14.66	6,745	421
RBC #2																		RBC #1			RBC #1
C	Q	P	C	Q	P	C	Q	P							C	Q	P	C	Q	P	C. Measure
535	0.437	235	1,276	0.187	239	685	0.464	318							0	0.033	0	727	1.09	792	741

measured discharge weighted TDS value at that station. The mean streamflow and TDS values used in Table 7.18 are more susceptible to the accumulation of background errors than an imput-output model of one point in time during stable streamflow periods.

The lower calculated TDS value at RBC#1 indicates that the groundwater or surface water TDS may be greater than measured. The groundwater TDS concentration was based on limited data since only two NCRP wells were finished in the Rosebud Creek alluvium. The absence of a continuous streamflow record at RBC#1 for the entire period of water quality data may cause discrepancies in determining the discharge-weighted TDS mean.

CHAPTER 8

MINING IMPACTS

INTRODUCTION

The hydrologic system and geologic framework of the Reservation and vicinity must be characterized before evaluating the hydrologic impacts of coal strip mining. The preceding chapters analyzed these elements and identified the parameters used to develop hydrologic and materials balance models of hypothetical mine sites.

The first two sections of this chapter discuss the literature, the methods used in predicting post mining spoil hydrology and water quality, and the hydrologic balance model. The latter two sections present the quantitative modeling for the Logging Creek, Buffalo Jump, and Indian Coulee Study Areas, and an extrapolation of the modeling technique for a hypothetical large scale mining situation in the region.

This chapter's analyses of mining impacts emphasize salinity related, post-mining effects on surface water and groundwater. The complex natural hydrologic and water quality systems, as well as complex post-mining water quality relationships, necessitated that the analyses be limited to TDS. It is recognized that other water quality impacts, such as sedimentation and heavy metals contamination, may cause greater concern than salinity in certain cases. However, due to the long term and potentially widespread effects on agricultural water uses, salinity impacts remain an important consideration.

The TDS of groundwater discharge from mine spoils was estimated from saturated paste data on overburden cuttings from each study area. Mine spoil hydrologic parameters, e.g. hydraulic conductivity, were taken from the literature on mine spoil research in the northern plains region. The surface water, groundwater, and geologic parameters of the models are based on the data presented in previous chapters. The models are water and materials balance equations of pre-mining and post-mining inputs and outputs of water and TDS. This is believed to be the first application of such modeling techniques to predict water quality impacts from mining in as large a region as the Northern Cheyenne Reservation.

Modeling results indicate that groundwater and spring water quality down gradient from mine spoils will decrease significantly, with TDS increases of from 20 to over 2,000 mg/l. Increases in the TDS of the Tongue River and Rosebud Creek down gradient from the Logging Creek and Indian Coulee mine sites will be minimal, within five percent of the natural TDS concentration. Extrapolation of the modeling techniques to large-scale regional mining scenarios indicates that significant impacts to surface water quality can be expected. Increases in TDS above current levels ranged from six percent to 46 percent.

GENERAL MINING IMPACTS AND PREVIOUS REPORTS

THE STRIP MINING OPERATION

In this region, a typical strip mine begins operations after extensive exploratory drilling. Drilling perforates the mineable coal, as well as the over and underlying earth materials. The mine is opened by blasting the consolidated sandstone and shale above and between the mineable coal seams. The material is removed by a dragline. The crushed overburden or mine spoil is placed on the land surface behind the initial cut, away from the planned direction of mine advance. Exposed coal is then removed by smaller electric shovels, and loaded onto trucks that carry coal from the mine. The second cut is made adjacent to the first. The dragline-removed spoils are placed in the trench left from the initial cut. This process proceeds until all suitable coal is removed. Usually, while the mine is advancing, spoil piles from older cuts are regraded by heavy equipment; stock-piled top soil is replaced; and revegetation efforts begin (Figure 8.1).

HYDROLOGIC RESEARCH OF MINING IMPACTS

The impacts of coal strip mining on the water resources of the northern great plains have only been studied in detail since the early 1970's, when state and federal laws required the preparation of environmental impact statements. Most mining impact research efforts have taken place in Montana, North Dakota and Wyoming, where seven of the largest strip-mining operations in the U.S.A. are located. These include AMAX Coal Company's Belle Ayr Mine in Wyoming, which produced over 16 million tons in 1978.

Early studies attempted to determine pre-mining hydrology and to predict the effect of mine dewatering on groundwater potentials in the mine area. Work in the past four years has been focused on mine dewatering analyses, post-mining water quality, mine spoil hydrology, and methods for predicting long-term impacts to the local and regional hydrologic systems. Nevertheless, as in the eastern part of the U.S.A. (Rogowski et al., 1977), there is presently no single technique available for assessing the degree of impact before mining, and for determining the long-term effects of strip mining on a given area.

W. A. Van Voast, of the Montana Bureau of Mines and Geology, has performed extensive site-specific hydrogeologic mining-impact research in the region. Research by Van Voast and others has included studies of pre-mining hydrologic conditions, dewatering calculations, monitoring of hydrologic changes during mining and post-mining, and spoil hydrology research (Van Voast, 1974; Van Voast and Hedges, 1975; Van Voast et al. 1975, 1976, 1977, 1978). Other hydrogeologic mining-impact research has been conducted in Montana by Arnold and Dollhoph (1977), Dollhoph et al. (1977), Woessner et al. (1979); in

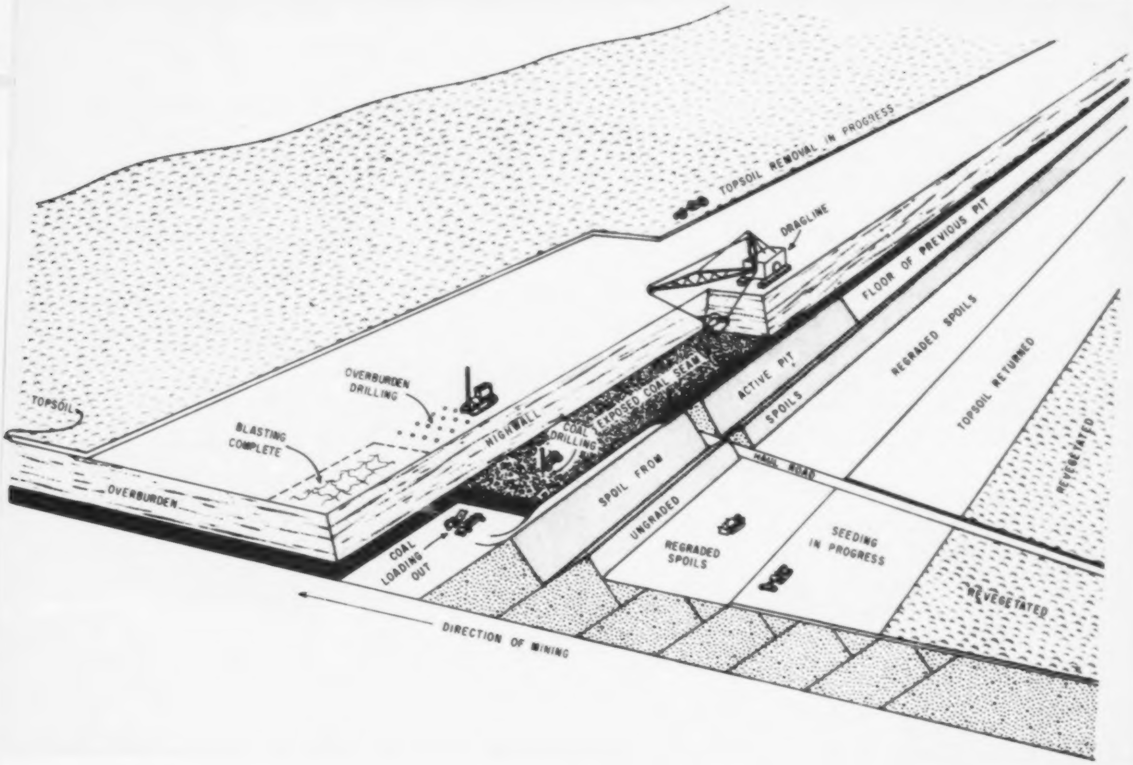

TOPSOIL REMOVAL IN PROGRESS
DRAGLINE
FLOOR OF PREVIOUS PIT
REGRADED SPOILS
TOPSOIL RETURNED
REVEGETATED
OVERBURDEN DRILLING
TOPSOIL
BLASTING COMPLETE
HIGHWALL
COAL DRILLING
EXPOSED COAL SEAM
ACTIVE PIT
SPOILS
HAUL ROAD
SPOIL FROM
UNGRADED
REGRADED SPOILS
SEEDING IN PROGRESS
OVERBURDEN
COAL LOADING OUT
REVEGETATED
DIRECTION OF MINING

Figure 8.1. Schematic of strip mine operation (from BIA, 1976).

Wyoming by Rahn (1976), Davis and Rechard (1977); in North Dakota by Moran et al. (1976, 1978), Croft et al. (1978), Groenewold et al. (1979); and in the three state region by Anonymous (1978). The modeling and prediction of post mining impacts has been attempted by Van Voast and Hedges (1975), McWhorter et al. (1976), Van Voast et al. (1976, 1977, 1978), Moran et al. (1978), and Groenewold et al. (1979). Additional efforts to assess site-specific impacts have been prepared by federal and state agencies in the form of environmental impact statements (USDI, 1974a, 1975, 1976a,b,c,d,e,f, 1977a,b, 1978c,d,e,f, 1979a).

Evaluation of the regional impacts of existing and proposed mining operations on the hydrologic system of the northern great plains has been attempted by regional study groups (NGPRP, 1974; USDI, 1974a 1978d; 1979 a,b). These programs have been qualitative in nature. More quantitative work has been funded by the U.S. Bureau of Mines (Hittman and Associates, Inc., 1977, 1978) to develop a digital model of the near-surface groundwater system in the Powder River Basin. The U.S. Environmental Protection Agency has also supported work to assess and identify water-quality problems associated with coal strip mining in the west, and to develop groundwater monitoring programs (Slawson, 1978).

Based on a review of the literature and current research efforts, a discussion of the general hydrologic impacts of surface coal mining on the hydrologic system of a given region is presented in three parts: (1) pre-mining; (2) mining; and (3) post-mining.

PRE-MINING IMPACTS

Unconfined, semi-confined, and confined groundwater systems within 60-120m (200 to 400 ft) of the surface are common in the western coal region. The impacts for the accepted practice of exploratory pre-mining drilling of from four to five holes per section over a large area, and for mine plan drilling on 15 m (50 ft) centers have not been addressed in the existing environmental impact statements. When pre-mining drilling perforates both shallow and deeper groundwater flow systems in an area, avenues for increased rates of groundwater mixing and migration are created. In the western United States, large areas may be explored, but not mined. However, as a result of exploration drilling, measureable groundwater impacts may occur. Wells used in determining pre-mining hydrogeologic conditions are usually emplaced in conjunction with or after mine plan drilling. If groundwaters begin to mix, and head equilibrium commences before observation wells are emplaced to establish impacts of mining, these wells will yield data which represent an altered hydrologic system. Without extensive pre-mine drilling information, the extent or severity of this impact cannot be fully assessed.

IMPACTS DURING MINING

Once mine plan drilling is completed, ammonium nitrate explosives are used to fracture the overburden for the initial mine cut. After the overburden and exposed coal are removed, the natural groundwater flow is intercepted, and groundwater is released from storage. As mining proceeds, additional groundwater can enter the mine from upward leakage through the fractured zones below the coal, if the proper hydraulic gradient exists (USDI, 1974a). A reversal of the hydraulic gradient resulting from dewatering operations can induce additional groundwater movement to the mine from nearby reservoirs and streams, if geologic conditions permit (Riordan, et al., 1978). In the mine, dewatering operations maintain a water level below the coal. Eventually a new equilibrium is established to control mine inflow. Water levels in wells, and spring flow surrounding the mine, may decline if they come within the influence of the cone of depression associated with the operation. Van Voast et al., (1976), stated that generally, hydrostatic pressure decline is not perceptible more than 100 meters (3,280 ft) from a typical western strip mine, and that changes are very gradual. However, as he discovered in his work, the rate of decline and area of influence is dependent on the site-specific hydraulic properties of the materials. At the West Decker mine, a water-level decline of three meters (10 ft) was noted at 1,500 m (4,920 ft) from the mine within the first year (Van Voast and Hedges, 1975). Two years later, the decline had doubled at the same distance. Van Voast, et al., (1976) noted that after four years of dewatering, rates of water level decline are diminishing.

Prediction of the groundwater inflow rates to a mine has been attempted by Van Voast and Hedges (1975). In order to utilize their technique, accurate data on the natural system and plan of mining are necessary. This detailed type of mine operation data is not available for the hypothetical mine sites on the Reservation.

The quality of the mine effluent has been found to be similar to the pre-mining groundwater with a few exceptions. Van Voast et al. (1976) noted that besides the natural groundwater constituents, the mine effluent at Decker contained nitrate concentrations ranging from less than one milligram per liter to 100 mg/l. These unnatural concentrations of nitrate were attributed to the ammonium nitrate explosive compounds used in blasting and/or nitrate compounds being dissolved from the overburden.

POST-MINING IMPACTS

After a mining operation has been completed, the once-saturated coal seam and the overlying rocks of the mine area are replaced by mine spoil. Van Voast and Hedges (1977) describe the character of the spoil as wasted coal at the mine base, coarse spoil material that has rolled down spoil piles during emplacement, thin portions of consolidated material between mine cuts, abandoned gravel haul roads, and blasted overburden material. Groundwater will begin to re-saturate the spoil materials when pumping of intercepted groundwater ceases and water is no longer moving into the spoils from all directions. Water will then begin to move through the spoils and continue down-gradient.

Mining operations physically alter the properties of the pre-mining earth materials that affect the occurrence, movement and quality of groundwater in the mine area. If the mining operation has only affected a small portion of a large groundwater flow system, the direction of the groundwater as it moves through the spoils and out of the mine site will follow the same general direction as the larger system. If the mining operation affects the major area of a flow system, post-mining paths may be altered, depending on the availability of recharge, and on the hydrologic properties of the spoils. Analyses of the post-mining properties of mine spoils were attempted by Van Voast (1974), Verma and Thames (1975), Farmer and Richardson (1976), McWhorter et al. (1976), Rahn (1976), Arnold and Dollhopf (1977) and Van Voast et al. (1977).

Attempts to identify the hydraulic properties of spoil-filled mine areas were conducted via pump tests on older re-saturated spoils; spoil infiltration tests; and laboratory permeameter tests on spoil samples. A summary of hydraulic conductivity and storage coefficient values from Wyoming and Montana mine spoils is presented in Table 8.1. The pump test hydraulic conductivities ranged from 0.021 to 18.3 m/d (0.07 tp 61 ft/d). Field infiltrameter tests and laboratory permeability analyses at eight mine sites indicated an average spoil hydraulic conductivity of 0.61 m/d (2 ft/d), with a range of 0.4 to 2.1 m/d (0.12 to 7 ft/d). Storage coefficients from three pump tests at different sites yielded values of 0.17, 0.23, and 0.1. Van Voast et al. (1976) noted wells finished in saturated spoils at the old Rosebud Mine at Colstrip reacted to barometeric pressure, indicating a storage coefficient of 10^{-5}. They postulated that the rubble zone at the base of the spoil might act as a confined system similar to the pre-mining coal system. Most researchers postulate that the spoils probably have a higher hydraulic conductivity than the undisturbed coal, sandstone, and shale; however, no generalization of the magnitudes of hydraulic conductivities have been described.

TABLE 8.1. SUMMARY OF LITERATURE ON HYDRAULIC PROPERTIES OF STRIP MINE SPOILS

TABLE 8.1. SUMMARY OF LITERATURE ON HYDRAULIC PROPERTIES OF STRIP MINE SPOILS

			Transmissivity		Hydraulic Conductivity		
Site of Test	Type of Test	Storage Coefficient	m^2/d	ft^2/d	m/d	ft/d	Reference
HIDDEN VALLEY MINE, WYO.	pump	0.17	137	1477	18.3	60.1	*
	infiltration				2.7	8.8	
	laboratory				0.4	1.3	
BIGHORN MINE, WYO.	pump	0.23	2.1	23	0.16	0.53	*
	infiltration		0.2	2.1	3.4	7.0	
	laboratory				0.4	1.3	
ROSEBUD MINE, MT.	infiltration				1.2	4	
	laboratory				0.5	1.5	*
DECKER MINE, MT.	infiltration				0.2	0.6	*
	laboratory				0.04	0.12	
WYODAK MINE, WYO.	infiltration				1.1	3.75	*
	laboratory				0.6	2.0	
BELLE AYR MINE, WYO.	infiltration				0.5	1.72	*
ROSEBUD MINE, MT.	pump		1.5	16	0.7	2.3	**
	range of pump tests				0.01 2.0	0.07 7	***
DECKER MINE, MT.	infiltration spoil 1 month old				0.8	2.8	****
	spoil 24 months old				0.07	0.24	

References:
* Rahn, 1976
** Van Voast and Hedges, 1977
*** Van Voast, 1973
**** Farmer and Richardson, 1976

Recharge rates from precipitation to the spoils have not been documented yet. With only two years of data, work by Arnold and Dollhopf (1977), and Dollhopf, et al. (1977), indicated that new spoils at Colstrip were receiving recharge from a basin in the study area where surface run-off collects, and that spoils in two other sites with only direct precipitation were not receiving measurable recharge. Soil moisture studies revealed that recharge would move to depths of 7 to 10 m (23 to 33 ft) below the surface of the spoils only to be lost by evapotranspiration, which reversed the downward movement.

The magnitude of post-mining impacts on groundwater quality are highly variable and difficult to predict. The variability in quality is a function of the quality of groundwater resaturating the spoils; the amount of recharge from precipitation that has reached the water table; and the type, distribution, and leachability of spoil materials. Van Voast and Hedges (1977) generalized their observations about spoil water quality at Colstrip as follows:

1. Young mine spoils (a few years old) contain water similar in chemical character to the surrounding undisturbed material.

2. Older mine spoils (30+ years) contain water more mineralized than the undisturbed material.

3. Water quality varies with depth.

4. The common ions of calcium, magnesium, sulfate, and trace metals (lead and nickel) are found in higher concentrations than in the undisturbed material.

5. Water quality varies spatially in the spoils, as well as in the undisturbed material.

As an example of the variability of spoil water quality, Van Voast and Hedges (1977) reported that TDS values in spoils approximately five years old at the Peabody Big Sky Mine near Colstrip showed a range of 600 - 1,500 mg/l.

POST-MINING FLOW SYSTEM AND WATER QUALITY MODELING

Post-mining flow system modeling was attempted previously, using the material-balance approach by Van Voast and Hedges (1975), and Van Voast et al. (1976, 1977). Montana State University (1978) attempted deterministic, digital modeling of post-mining hydrology with little success because of insufficient data on post-mining aquifer parameters and on chemical transport (R. W. Davis, pers. commun., 1979). McWhorter et al. (1978) met with mixed success in such modeling due to over-parameterization. Croft et al. (1978) and Moran et al. (1978) have attempted to provide a geochemical framework for modeling post-mining hydrologic impacts at various North Dakota Sites.

Saturation paste extracts were previously used by McWhorter et al. (1976) in determining spoil water quality for a strip mine operation in Colorado, and by Van Voast and Hedges (1975) in forecasting spoil water quality at the Decker, Montana mines. D. B. McWhorter (pers. commun., 1978) suggests that the average saturation-paste TDS values for a series of composite samples of overburden drill cuttings may not permit prediction of spoil water quality at an individual well finished in the spoil, while it would be representative of the general quality of spoil water.

Post-mining impacts are not restricted to the mine site. Mine spoil water will move away from the site in the direction of decreasing hydraulic head. Poor quality groundwater resulting from spoil leaching can degrade down-gradient groundwater supplies and surface-water bodies at points of groundwater discharge. The spoil water may also move into underlying groundwater systems, if hydraulic conditions permit. Results of studies attempting to determine hydrologic parameters of spoil material and the associated groundwater system indicate water-quality impacts may last for long periods of time after mining operations cease.

METHODS

Quantification of potential mining impacts in this study are focused exclusively on post-mining effects on groundwater and surface water TDS concentrations. Examination of other water quality impacts was beyond the scope of this project.

Post-mining impacts were quantified in the vicinity of three hypothetical mine sites on the Reservation. The criteria used to select the priority areas are discussed in CHAPTER 5. The three hypothetical mine sites, their locations, and yields are:

1. Logging Creek site located in the Logging Creek Priority Study Area (Figure 8.2), near Tongue River. This mine would sustain an annual yield of 9 million metric tons for 30 years, assuming an average coal thickness of 18.3 m (60 ft) and a stripping ratio of 3 to 1.

2. Buffalo Jump site located in the Buffalo Jump Priority Study Area in the plateau region at the headwaters of Muddy Creek, Lame Deer Creek and Clubfoot Creek (Figure 8.3). Assuming an average coal thickness of 15.2 m (50 ft) and a 3 to 1 stripping ratio, the mine site would yield 4.5 million metric tons for 30 years.

3. Indian Coulee mine site located in the Indian Coulee Priority Study Area, north of U.S. 212 and Rosebud Creek about halfway between the towns of Busby and Lame Deer (Figure 8.4). The mine site would sustain an annual yield of 4.5 million metric tons for 30 years, assuming an average coal thickness of 6.1 m (20 ft) and a stripping ratio 3 to 1.

GROUNDWATER FLOW SYSTEM DEFINITION

A necessary prerequisite to quantifying mining impacts is the definition of the groundwater flow system in the vicinity of the hypothetical mine. The techniques used to define a flow system are described in CHAPTER 6. The hydrogeologic characteristics for a generalized hypothetical mine site are assumed to be identical to those described for the respective Priority Study Area in CHAPTER 6. It is also assumed that the hydrogeologic flow systems in existence after mining will be similar to the original system. The only significant difference after mining will be that recharge occurs to the spoils, due to their more porous nature and the lack of confining layers.

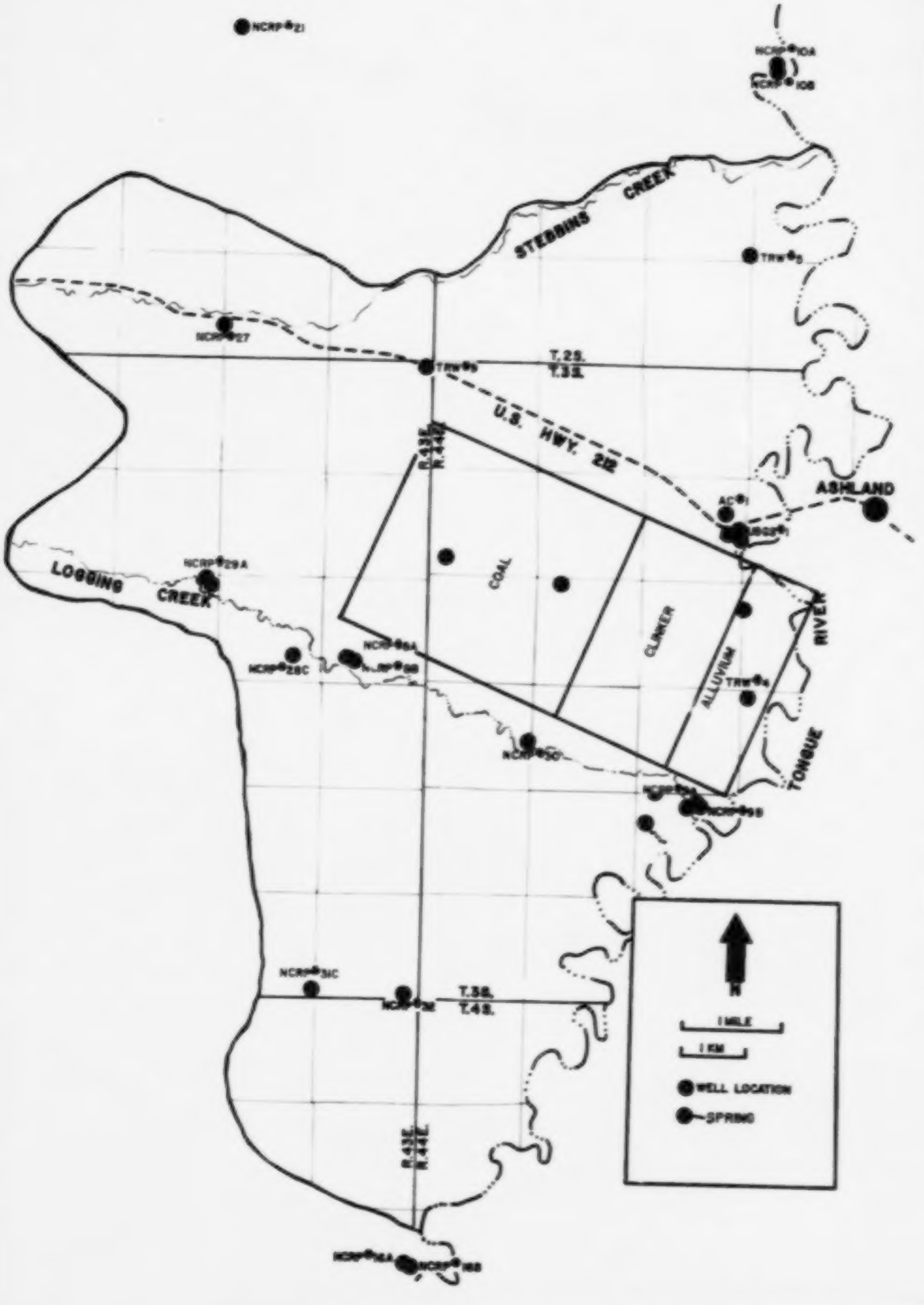

NCRP 21
NCRP 10A
NCRP 10B
STEBBINS CREEK
TRW 3
NCRP 27
TRW
T.2S.
T.3S.
U.S. HWY. 212
R.43E.
R.44E.
ASHLAND
AC 1
COAL
CLINKER
ALLUVIUM
RIVER
TONGUE
TRW 4
NCRP 29A
LOGGING CREEK
NCRP 28C
NCRP 30
NCRP 31C
NCRP 32
T.3S.
T.4S.
R.43E.
R.44E.
NCRP 16A
NCRP 16B
N
1 MILE
1 KM
WELL LOCATION
SPRING

Figure 8.2. Location of the Logging Creek Mine Site.

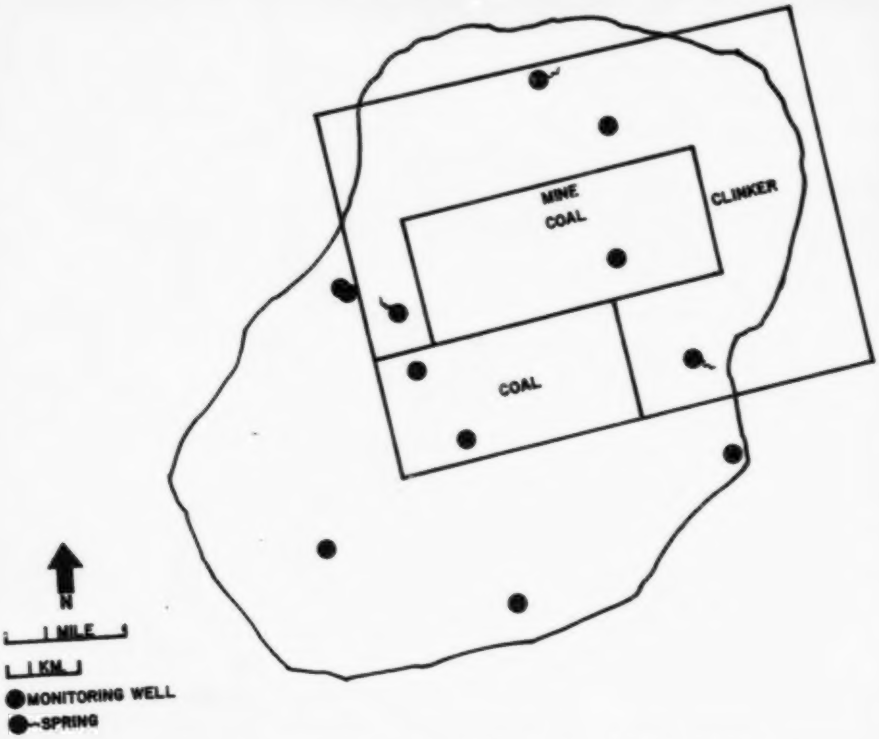


Figure 8.3. Location of Buffalo Jump Mine Site.

MATERIAL BALANCE MODEL

A material balance model was used to determine the changes in TDS for groundwater discharging to streams and springs in the hypothetical mine site vicinity, and the TDS changes for Tongue River and Rosebud Creek.

The following equations were used to determine water quality changes in the conceptual system (Figure 8.5), which assumes that the system is at steady state and that no chemical reactions occur down gradient of the spoils:

$$GW_{TDS} = \frac{(COAL_I + SPOIL_R) \times SPOIL_{TDS} + OTHER_R \times OTHER_{TDS}}{(GW_D + SPOIL_R)}$$

where:

GW_{TDS} is TDS concentration of groundwater outflow from the ground water system after equilibrium is established once the spoils have been resaturated, mg/l;

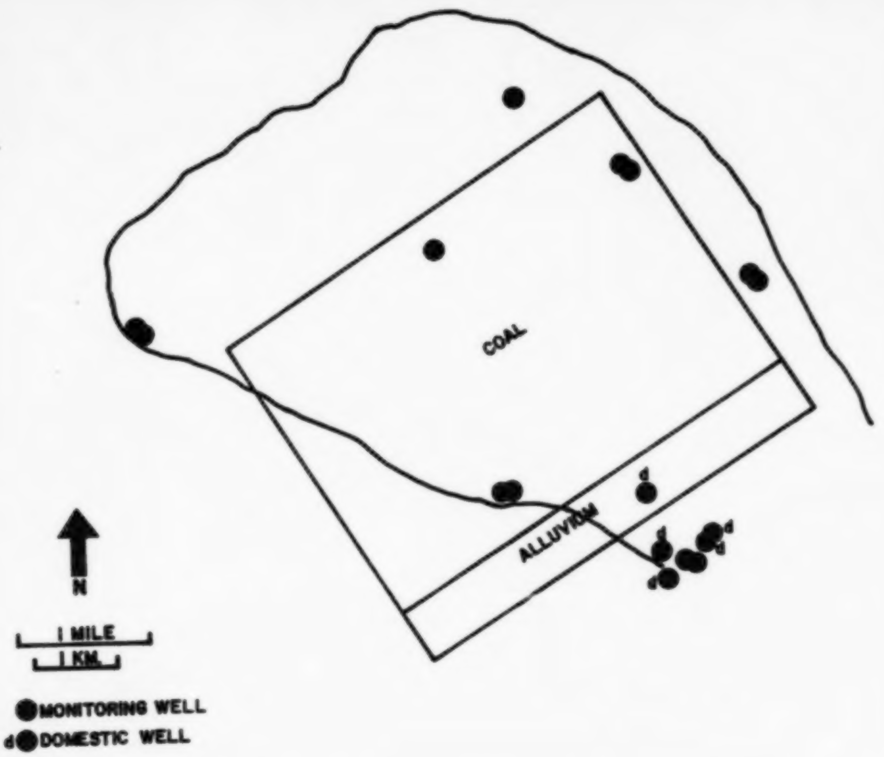


Figure 8.4. Location of Indian Coulee Mine Site.

$COAL_I$	is the natural groundwater inflow to the coal seams prior to mining, m^3/day;
$SPOIL_R$	is the recharge that occurs to the spoils, m^3/day;
$SPOIL_{TDS}$	is the TDS of the water leaving the spoils and entering the undisturbed groundwater system, mg/l;
$OTHER_R$	is the groundwater that enters the system downgradient from the mine site, which includes recharge to the alluvium, clinker, and inflow from deep systems;
$OTHER_{TDS}$	is the average TDS of the groundwater that enters the system downgradient from the mine;
GW_D	is the pre-mining outflow from the groundwater system.

All parameters in equation (1) were determined from field data except $OTHER_{TDS}$.

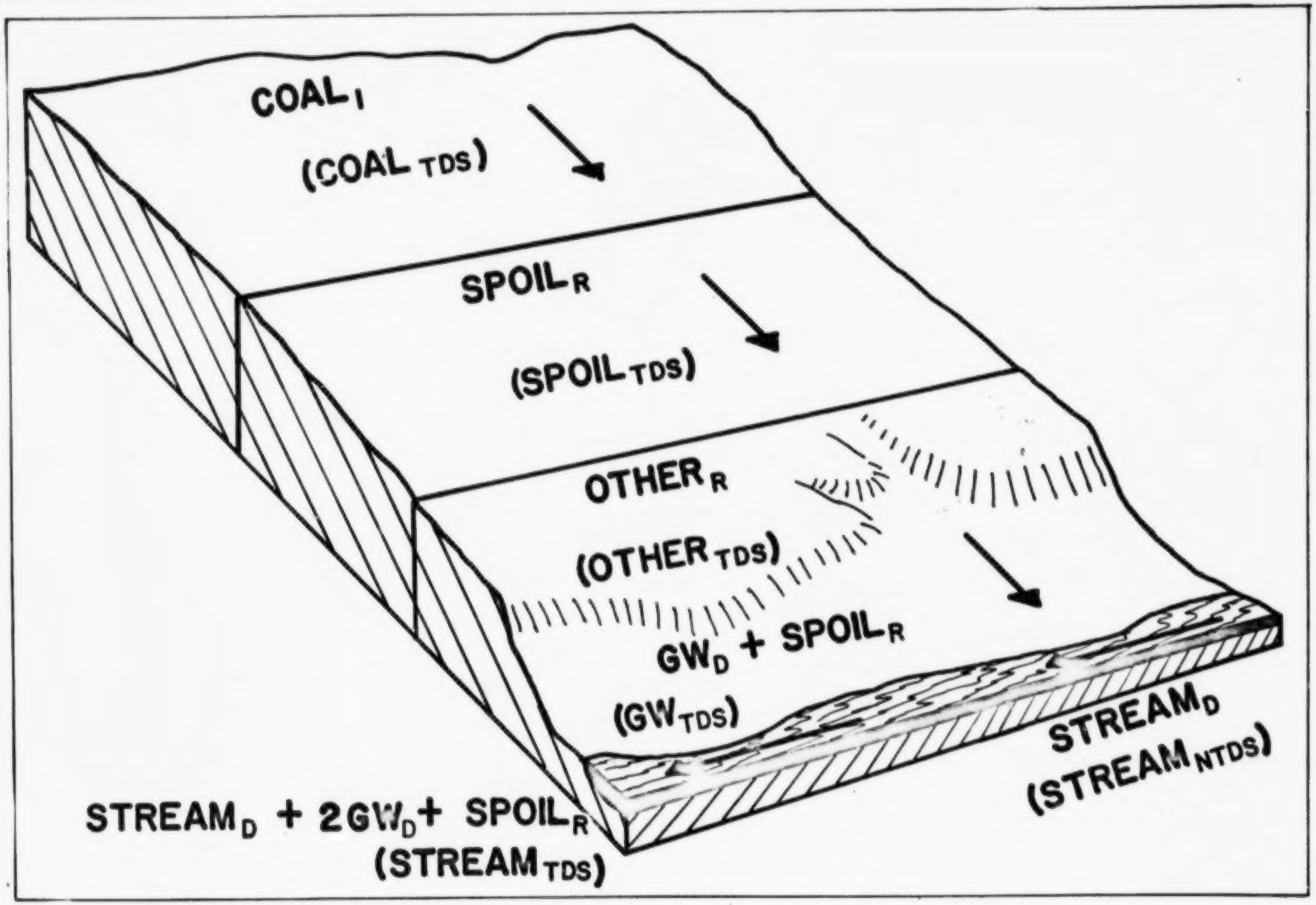

$COAL_I$
$(COAL_{TDS})$
$SPOIL_R$
$(SPOIL_{TDS})$
$OTHER_R$
$(OTHER_{TDS})$
$GW_D + SPOIL_R$
(GW_{TDS})
$STREAM_D$
$(STREAM_{NTDS})$
$STREAM_D + 2GW_D + SPOIL_R$
$(STREAM_{TDS})$

Figure 8.5. Schematic of a modeled area.

The following equation was used to determine $OTHER_{TDS}$:

$$OTHER_{TDS} = \frac{GW_D \times GW_{NTDS} - (COAL_I \times COAL_{TDS})}{OTHER_R}$$

Where:

$COAL_{TDS}$ is the TDS concentration of groundwater flowing in the coal seam, mg/l;

GW_{NTDS} is the pre-mining groundwater quality of the water discharging to the stream in the vicinity of the mine, mg/l;

Water changes in the receiving stream were then determined with the following equation:

$$STREAM_{TDS} = \frac{STREAM_F \times STREAM_{NTDS} + (GW_D + SPOIL_R) \times GW_{TDS}}{STREAM_F + SPOIL_R + GW_D}$$

Where:

$STREAM_{TDS}$ is the TDS concentration in the stream, into which the groundwater affected by the mine discharges, downstream from the affected area, mg/l;

$STREAM_F$ is the streamflow upstream from the mine area, m^3/day;

$STREAM_{NTDS}$ is the TDS concentration in the stream upstream from where the polluted groundwater enters the stream, mg/l.

REQUIRED PARAMETERS

The physical properties required as input parameters for the materials balance model are: flow of stream upstream from the mined area, TDS concentrations of the stream, natural groundwater inflow into the stream in the section influenced by mining, natural TDS of groundwater discharging into the stream, groundwater inflow into the mine site, TDS of the groundwater inflow, other groundwater inflow to the system, water quality of groundwater leaving the spoils and the recharge rate to the spoils.

(1) $STREAM_D$

Stream flows in the vicinity of the modeled area were interpolated from the gaging stations on the Tongue River and Rosebud Creek located at the southern and northern Reservation boundaries.

(2) $STREAM_{NTDS}$

The total natural dissolved solids concentrations of the streams in the vicinity of the modeled area were measured monthly during 1976 and 1977 and during low flow periods. The fifty percentile TDS concentration and discharge weighted mean TDS were calculated from the monthly values.

(3) GW_D

Groundwater inflow to the Tongue River and Rosebud Creek was determined from seepage runs.

(4) GW_{NTDS}

The natural TDS of groundwater discharging to the Tongue River and Rosebud Creek in the vicinity of the modeled area was estimated by averaging the TDS concentrations of wells located in the alluvium adjacent to the river.

(5) $COAL_I$

The natural groundwater flow through the coal seam was estimated using Darcy's law. The potentiometric gradient was determined from wells finished in the Knobloch coal seam. The thicknesses of the seams were determined from borings, and the hydraulic conductivity was determined by eleven short term one well pump tests. It is assumed that after mining is completed the groundwater inflow to the spoils will be equal to the groundwater flow through the coal seams prior to mining.

(6) $COAL_{TDS}$

The TDS concentrations of the groundwater flowing into the mine area were calculated by averaging the TDS concentrations determined from water samples taken from wells finished in coal seams, located in the hypothetical mine site or upgradient from the mine site.

(7) $OTHER_R$

The quantity of groundwater entering the system by recharge down gradient from the proposed mine area, and by discharge from deep flow systems, was determined by subtraction. $OTHER_R$ was broken down as groundwater recharge to the clinker, recharge to the alluvium, and inflow to the alluvium from deep flow systems. The recharge rates were calculated from well hydrographs, and the discharge from the deeper systems was determined by subtraction. This breakdown was not necessary for purposes of calculating changes in stream TDS, as it does not improve the predictive capabilities of the model.

(8) $SPOIL_{TDS}$

Saturation extract analyses of twenty seven samples of drill cuttings from the hypothetical mine site areas were run by D. B. McWhorter at Colorado State University (pers. commun., 1978). The saturation extract TDS values were averaged to obtain a TDS value which is assumed to be representative of quality of the spoil recharge, as it enters the spoil groundwater system. Composite leachate columns of drill cuttings were leached with groundwater from the mine site and with distilled water to simulate recharge. It was determined that the spoils are readily leachate by both the pre-mining groundwater and distilled water.

(9) $SPOIL_R$

A range of spoil recharge rates from 0.0031 to 0.031 m/y was used. The lower rate was based on the rate of recharge measured from well hydrographs for the period 1975-1977 to unconfined sandstone, shale and coal. The higher rate was employed as a worse case figure.

RESULTS AND DISCUSSION

LOGGING CREEK MINING IMPACTS

Pre-Mining Conditions

The model represents groundwater movement through the volume of mineable coal, clinker, underlying shale, sandstone, and alluvium, 3,220 m (10,562 ft) in length perpendicular to the direction of groundwater flow. The area of the model extended from 3,543 m (11,614 ft) west of the coal-clinker boundary, east to the Tongue River.

Groundwater flows through the site from northwest to southeast, discharging into the clinker and alluvial materials, and eventually into the Tongue River. The pre-mining groundwater flow and corresponding TDS water quality data are presented in Figure 8.6. Groundwater discharge from the southeastern mine boundary to the clinker zone is 359.4 m^3/d (12,692 ft^3/d). This water moves through the clinker zone where 436 m^3/d (15,043 ft^3/d) of recharge enters the system. A total of 785 m^3/d (27,721 ft^3/d) of water either seeps out as springs at the clinker boundary, running downgradient and re-entering the alluvial materials, or migrates downward through fractured basal clinker to sandstone and shale in direct contact with alluvium. The quantity of water entering the alluvium is 518 m^3/d (18,292 ft^3/d) from recharge by precipitation, plus 1,985 m^3/d (70,098 ft^3/d) seepage from the clinker zone and deeper flow systems. Groundwater discharge to the Tongue River totals 3,288 m^3/d (116,112 ft^3/d), and has an average TDS of 1,140 mg/l.

Post-Mining Impacts

When mining is completed, spoil material is backfilled to an approximate depth of 61 m (200 ft), in the mine pit. Groundwater in the surrounding coal and clinker will flow to the site under the existing gradient, and begin re-saturation of the spoils.

The post-mining material balance model of the Logging Creek mine area is presented in Figure 8.7. The parameters used in the model are listed in Table 8.2. Post-mining recharge rates of 0.0031 to 0.031 m were assumed for spoil

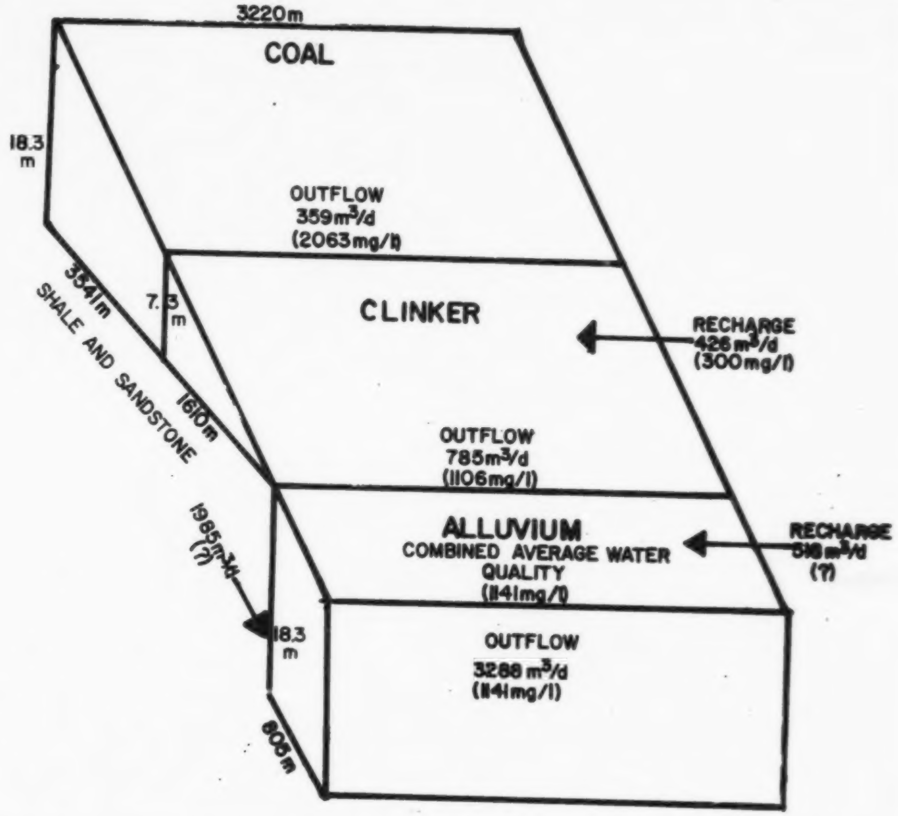

3220m
COAL
18.3 m
OUTFLOW
359m³/d
(2063mg/l)
3541m
SHALE AND SANDSTONE
7.3 m
CLINKER
RECHARGE
426m³/d
(300mg/l)
1610m
OUTFLOW
785m³/d
(1106mg/l)
1985m³/d
(?)
ALLUVIUM
COMBINED AVERAGE WATER
QUALITY
(1141mg/l)
RECHARGE
516m³/d
(?)
18.3 m
OUTFLOW
3288 m³/d
(1141mg/l)
806m

Figure 8.6. Pre-mining groundwater system at Logging Creek mine site.

recharge. Outflow from the mine site increases from the pre-mining value of 359 m^3/d (12,692 ft^3/d) to the post-mining value range of approximately 456 m^3/d (16,110 ft^3/d) to 1,327 m^3/d (46,890 ft^3/d) depending on the recharge rate. The net outflow to the Tongue River increases from 30.1 to 301 m^3/d/km (1,709 ft^3/d/mi). The TDS of groundwater discharge to the Tongue River is dependent on the rate of flow. Changes in water quality of Tongue River and of groundwater discharge to the river are listed in Table 8.3

Analyses of the water quality data indicate that a single mine in the Logging Creek area will have a significant impact on groundwater quality, but only a minimal impact on Tongue River water quality. In both cases, however, water quality impacts will not be short term. Analyses of leaching experiments showed that most leachable solids will be removed by the flushing of the initial pore volume of water through the spoils. Based on recharge rates of 0.0031 m/y (0.01 ft/y) to 0.03 m/y (0.1 ft/y), and an assumed effective spoils porosity of 0.1, it would take from 140 to 1,400 years to pass one pore volume of recharge through unsaturated spoil (assuming the lower 18.2 m (60 ft) of

TABLE 8.2. PARAMETERS USED IN THE MASS BALANCE MODEL OF THE LOGGING CREEK MINE SITE

$STREAM_F$	
Average flow	1.23×10^6 m^3/day
50% flow	0.49×10^6 m^3/day
Low flow	0.14×10^6 m^3/day
$STREAM_{NTDS}$	
At average flow	270 mg/l
At 50% flow	623 mg/l
At low flow	836 mg/l
GW_D	3288 m^3/day
GW_{NTDS}	1141 mg/l
$OTHER_R$	2929 m^3/day
$OTHER_{TDS}$*	1028 mg/l
$COAL_I$	359 m^3/day
$COAL_{TDS}$	2063 mg/l
$SPOIL_R$	96.8-968 m^3/day
$SPOIL_{TDS}$**	4100 mg/l

* Calculated using equation 2.

** Based on drill cuttings from NCRP wells 8A, 27 and 29.

the spoil is resaturated by groundwater).

The leaching process will continue long after the 30 year life of the mine. Impacts to the water quality of the clinker and alluvial units downgradient from the mine and the Tongue River will not be apparent immediately at the completion of mining. The time required to resaturate the mine spoils and establish a flow system is unpredictable at this time; however, once the system has been reestablished, groundwater leachate travel-times can be predicted with Darcy's law, assuming only convective transport. A summary of these data are presented in Figure 8.8. Changes in water quality would be discernable in the clinker and alluvium within a very short time after a groundwater flow system has been reestablished. However, the low hydraulic conductivity of the spoil, the small rates of recharge, and large volume of spoils would result in the production and outflow of high TDS water from the mine site for hundreds of years.

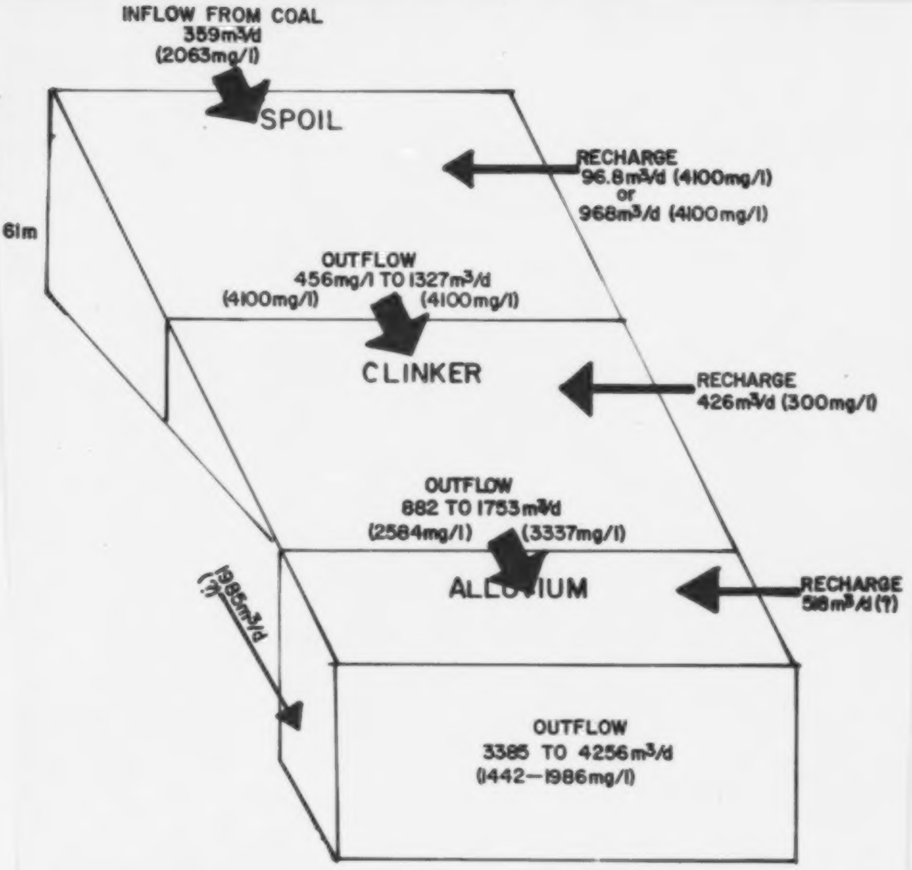

INFLOW FROM COAL
359m3/d
(2063mg/l)
SPOIL
RECHARGE
96.8m3/d (4100mg/l)
or
968m3/d (4100mg/l)
61m
OUTFLOW
456mg/l TO 1327m3/d
(4100mg/l)
(4100mg/l)
CLINKER
RECHARGE
426m3/d (300mg/l)
OUTFLOW
882 TO 1753m3/d
(2584mg/l)
(3337mg/l)
ALLUVIUM
RECHARGE
518m3/d (?)
1985m3/d
(?)
OUTFLOW
3385 TO 4256m3/d
(1442—1986mg/l)

Figure 8.7. Post-mining groundwater system at Logging Creek mine site.

TABLE 8.3. IMPACTS OF THE HYPOTHETICAL LOGGING CREEK MINE ON WATER QUALITY OF THE TONGUE RIVER AND ON THE QUALITY OF GROUNDWATER DISCHARGING TO THE TONGUE RIVER

		Post Mining TDS	
	Natural TDS	0.0031 m/y Recharge	0.031 m/y Recharge
Discharging Groundwater TDS (mg/l)	1141	1442	1982
Streamflow TDS (mg/l) at:			
mean annual flow	275	278	281
50 percentile flow	630	636	642
measured low flow	850	864	883

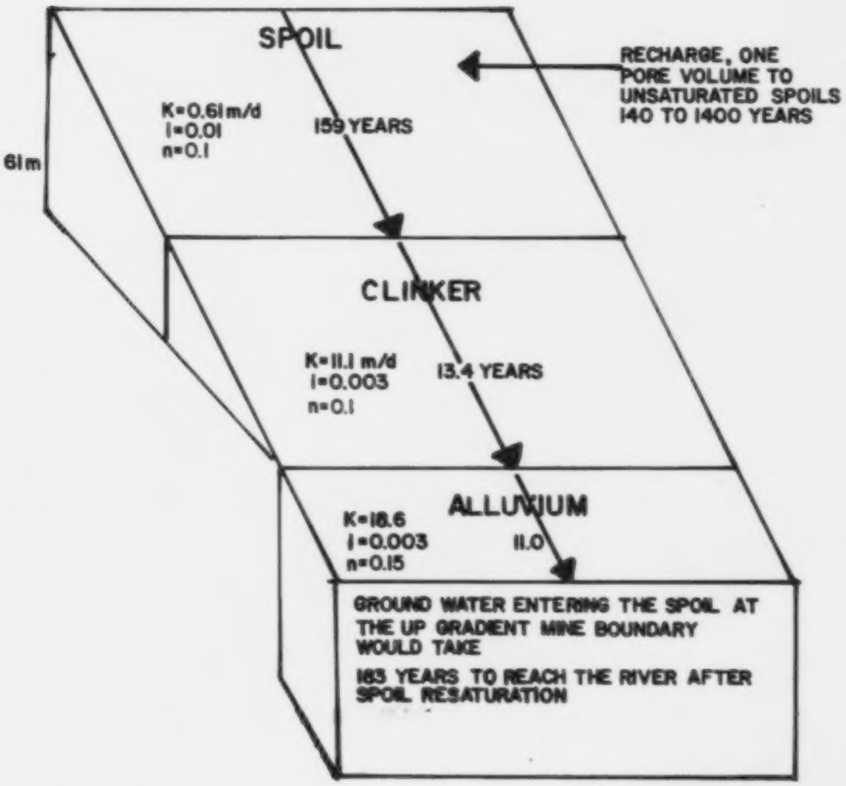

SPOIL
RECHARGE, ONE PORE VOLUME TO UNSATURATED SPOILS 140 TO 1400 YEARS
K=0.61m/d
i=0.01
n=0.1
159 YEARS
61m
CLINKER
K=11.1 m/d
i=0.003
n=0.1
13.4 YEARS
ALLUVIUM
K=18.6
i=0.003
n=0.15
11.0
GROUND WATER ENTERING THE SPOIL AT THE UP GRADIENT MINE BOUNDARY WOULD TAKE
183 YEARS TO REACH THE RIVER AFTER SPOIL RESATURATION

Figure 8.8. Groundwater travel time at Logging Creek mine site.

BUFFALO JUMP MINE SITE IMPACTS

Pre-Mining Conditions

The model represents groundwater movement from the unburned coal to the south into the mine site. Movement from the mine site flows to the north, west, and southeast of the site. The pre-mining groundwater flow conditions are presented in Figure 8.9. Groundwater discharge is 36 m^3/d (1,271 ft^3/d) along the 3,879 m (12,725 ft) northern mine boundary; 29.9 m^3/d (1,056 ft^3/d) along the 1,610 m (5,280 ft) western mine boundary; and 13.6 m^3/d (480 ft^3/d) along the 1,465 m (4,085 ft) southeastern mine boundary. This gives a total discharge of 79.5 m^3/d (2,807 ft^3/d) from the mine site. Groundwater enters the area along the 2,415 m (7,870 ft) southern boundary at a rate of 48.8 m^3/d (1,581 ft^3/d). This indicates that 30.7 m^3/d (1,084 ft^3/d) of water is recharged to the system from precipitation, which corresponds to a recharge rate of .0018 m/y (0.006 ft/y).

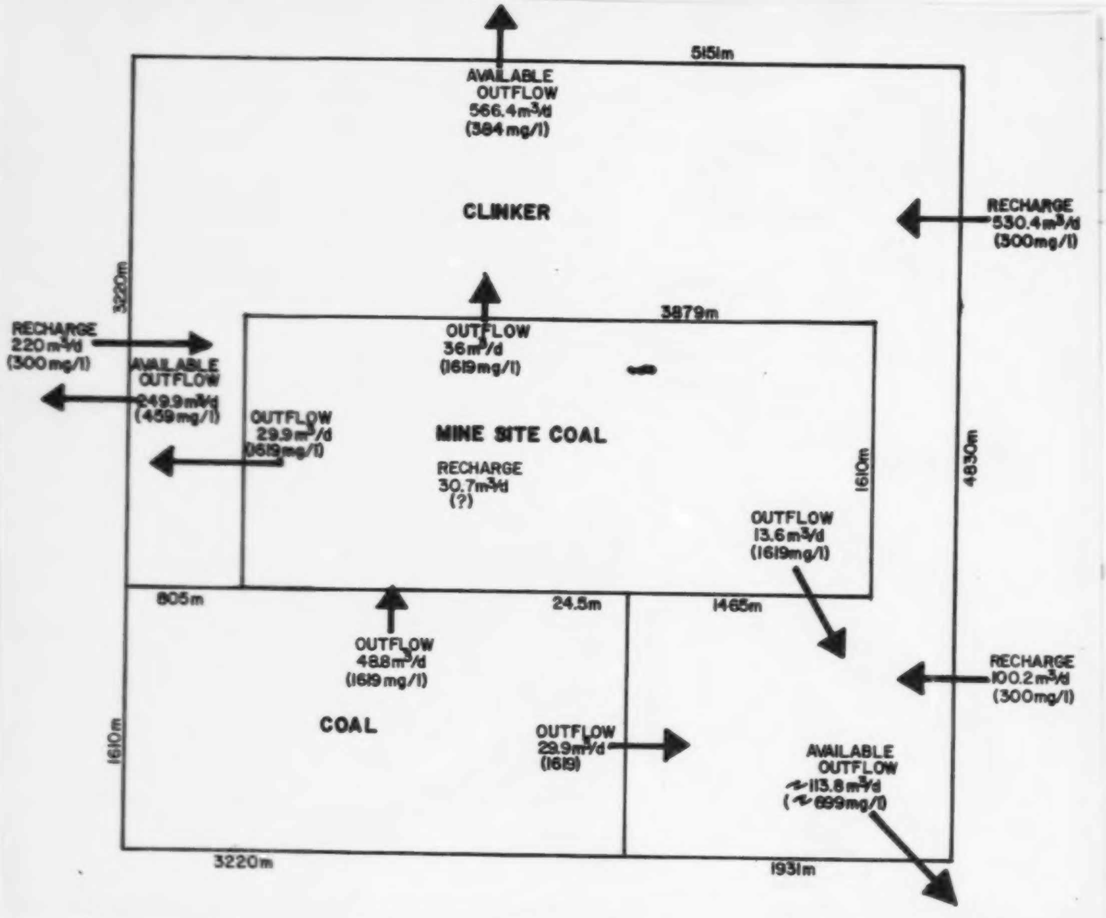

AVAILABLE
OUTFLOW
566.4m³/d
(384 mg/l)
515lm
CLINKER
RECHARGE
530.4m³/d
(300mg/l)
3220m
RECHARGE
220 m³/d
(300 mg/l)
AVAILABLE
OUTFLOW
249.9m³/d
(459 mg/l)
OUTFLOW
36m³/d
(1619mg/l)
3879m
OUTFLOW
29.9m³/d
(1619mg/l)
MINE SITE COAL
RECHARGE
30.7m³/d
(?)
1610m
4830m
OUTFLOW
13.6 m³/d
(1619mg/l)
805m
24.5m
1465m
OUTFLOW
48.8m³/d
(1619 mg/l)
RECHARGE
100.2 m³/d
(300mg/l)
COAL
OUTFLOW
29.9m³/d
(1619)
AVAILABLE
OUTFLOW
~113.8m³/d
(~699mg/l)
1610m
3220m
1931m

Figure 8.9. Pre-mining groundwater system at Buffalo Jump mine site.

The rates of groundwater outflow from each clinker area were also calculated. However, as described in CHAPTER 6, not all of this water discharges as springs. Some moves downward to recharge the deeper flow systems.

The average TDS of the groundwater outflow from the coal is 1,619 mg/l. The TDS of the groundwater discharge from the clinker in the north, west, and the southeast were determined from equation 2. Actual TDS values of 458 mg/l at Bixby Spring in the clinker zone to the north and 664 mg/l at B. Heart Spring in the clinker zone to the southeast correspond fairly well with the calculated TDS of the available clinker outflow.

Post-Mining Impacts

Changes in Groundwater Flow

When mining is completed, spoil material is backfilled to an approximate depth of 61 m (200 ft) in the mine pit. Groundwater in the coal and clinker surrounding the site will flow to the site under the existing gradients and begin resaturation of the spoils. It is assumed that a hydrogeological flow system similar to the pre-mining system will exist. The major change in the system will be the recharge received over the surface area of the mine, due to the porous nature of the spoils and the absence of the confining layers. The post-mining material balance model for the Buffalo Jump site is shown in Figure 8.10. The parameters used in the model are listed in Table 8.4. Three material balance models were formulated. One describes groundwater flow and quality towards the north in the Lame Deer Creek drainage, the second describes flow and quality to the west in Muddy Creek drainage, and the third describes flow and quality towards the southeast in the Clubfoot Creek drainage. Much of the groundwater flow to the north, west, and southeast discharges in springs at the base of the clinker formations. Post-mining recharge rates of 0.0031 to 0.031 m^3/y were assumed for spoil recharge. This would mean that the post-mining flow, from the mine site could increase from the pre-mining 79.5 m^3/d (2,807 ft^3/d) to 132.5 to 609.0 m^3/d (4,679 to 21,538 ft^3/d).

Water Quality Changes in the Drainage North of the Mine

Outflow of spoil water from the mine site to the north would combine with clinker recharge water making 590 to 806 m^3/d (20,835 to 28,462 ft^3/d) of groundwater with a TDS range of 544 to 1,122 mg/l at a flow of 0.05 m^3/sec (1.7 ft^3/sec). The spoil water reaching the springs and Lame Deer Creek will increase the TDS levels of those waters. The average TDS of springs near the northern mine boundary is 454 mg/l.

Water Quality Changes in the Drainage West of the Mine

Outflow from the mine, combined with clinker recharge to the west, would make available 270 to 450 m^3/d (9,535 to 15,891 ft^3/d) of groundwater with a TDS of 744 to 1,527 mg/l to recharge deeper aquifer systems and Muddy Creek. The average TDS of springs and small streams near the western boundary is 427 mg/l. Muddy Creek water has an average TDS of 1,106 mg/l at a flow of 0.8 m^3/sec (2.7 ft^3/sec) near its mouth. This would impact water quality measureably in the upper reach of Muddy Creek.

Water Quality Changes in the Drainage to the Southeast of the Mine

Flow to the southeast of the mine through the southeastern clinker zone would make available 153 to 234 m^3/d (5,403 to 8,263 ft^3/d) of groundwater with a range of TDS of 934 to 1,545 mg/l for recharge of deeper systems and discharge into the Clubfoot Creek drainage. The average TDS of springs discharging near the southeastern mine boundary is 1,380 mg/l. Water quality of springs and streams in the Clubfoot Creek and Cook Creek drainage would be somewhat degraded. A summary of predicted water quality impacts is given

TABLE 8.4. PARAMETERS USED IN MASS BALANCE MODELS OF THE BUFFALO JUMP MINE SITE

Parameters used to calculate water quality changes north of the mine.

GW_D	566 m^3/d
GW_{NTDS}*	384 mg/l
$OTHER_D$**	530 m^3/d
$OTHER_{TDS}$**	300 mg/l
$COAL_I$	36 m^3/d
$COAL_{TDS}$	1619 mg/l
$SPOIL_R$	24 - 240 m^3/d
$SPOIL_{TDS}$***	2700 mg/l

* Calculated with equation 2

** Includes only clinker recharge

*** Based on drill cuttings from NCRP 4, 22, and 26

Parameters used to calculate water quality changes west of the mine.

GW_{D}	250 m^3/day
GW_{TDS*}	458 mg/l
$OTHER_{D**}$	220 m^3/day
$OTHER_{TDS**}$	300 mg/l
$COAL_{I}$	29.9 m^3/day
$COAL_{TDS}$	1619 mg/l
$SPOIL_{R}$	20 - 200 m^3/day
$SPOIL_{TDS}$	2700 mg/l

* Calculated with equation 2.
** Composed only of clinker recharge.

Parameters used to calculate water quality changes southeast of the mine.

GW_{D}	144 m^3/day
GW_{TDS*}	724 mg/l
$OTHER_{D**}$	130 m^3/day
$OTHER_{TDS**}$	630 mg/l
$COAL_{I}$	13.6 m^3/day
$COAL_{TDS}$	1619 mg/l
$SPOIL_{R}$	9 - 90 m^3/day
$SPOIL_{TDS}$	2700 mg/l

* Calculated with equation 2
** Composed of clinker recharge, plus inflow from east to west.

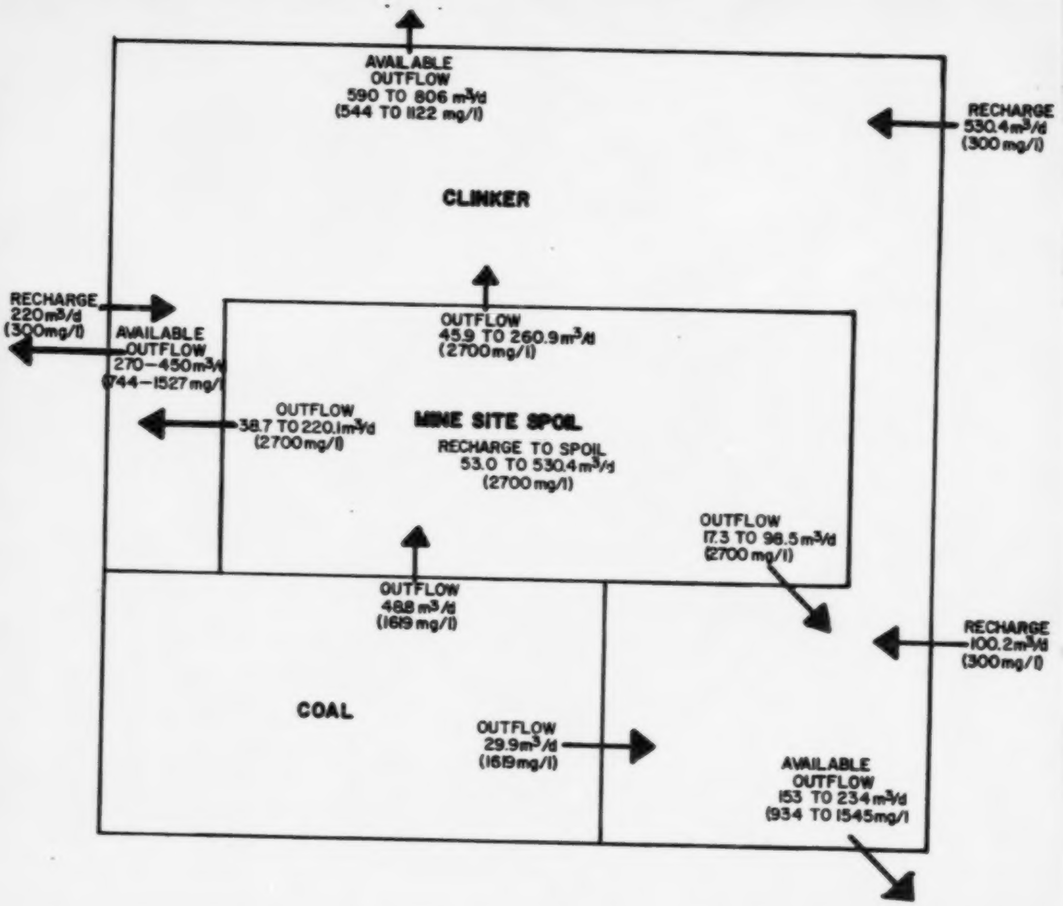

AVAILABLE OUTFLOW 590 TO 806 m³/d (544 TO 1122 mg/l)
RECHARGE 530.4 m³/d (300 mg/l)
CLINKER
RECHARGE 220 m³/d (300mg/l)
AVAILABLE OUTFLOW 270–450 m³/d (744–1527 mg/l)
OUTFLOW 45.9 TO 260.9 m³/d (2700mg/l)
OUTFLOW 38.7 TO 220.1 m³/d (2700mg/l)
MINE SITE SPOIL
RECHARGE TO SPOIL 53.0 TO 530.4 m³/d (2700 mg/l)
OUTFLOW 17.3 TO 98.5 m³/d (2700 mg/l)
OUTFLOW 48.8 m³/d (1619 mg/l)
RECHARGE 100.2 m³/d (300mg/l)
COAL
OUTFLOW 29.9 m³/d (1619 mg/l)
AVAILABLE OUTFLOW 153 TO 234 m³/d (934 TO 1545 mg/l)

Figure 8.10. Post-mining groundwater system at Buffalo Jump mine site.

in Table 8.5.

Time Required for Impacts to Become Significant

Once the post-mining flow system has been reestablished and water from the spoil area moves out of the mine boundaries into the clinker, it will take a relatively short time before the spoil water will reach the springs to the north, west, and southeast of the area. Assuming pre-mining gradients, a clinker hydraulic conductivity of 5.4 m/d (18 ft/d), and an effective porosity of 0.1 for the clinker, it would take only 27 years for spoil water to reach the north and west springs at the base of the clinker and 14 years to reach the springs found to be southeast. Water quality impacts, however, would not be short- term. Based on recharge rates described and 0.1 as the porosity of the 45.7 m (150 ft) of spoil, it would take from 150 to 1,500 years to pass one pore volume of recharge through the unsaturated spoil (assuming that 15.2 m (50 ft) of the spoil was resaturated by groundwater). These analyses indicate that the leaching process will continue for hundreds

TABLE 8.5. SUMMARY OF SPRING WATER QUALITY CHANGES NEAR THE BUFFALO JUMP MINE SITE

		Post Mining TDS mg/l	
	Natural TDS mg/l	0.0031 m/yr	0.031 m/yr recharge
Springs at base of clinker to north in Lame Deer Creek drainage	384	544	1122
Springs at base of clinker to west in Muddy Creek drainage	458	744	1527
Springs at base of clinker to southeast in Clubfoot Creek drainage	724	934	1545

of years after water quality degradation is first recorded in local springs. The higher elevation of the mine site, and higher average annual precipitation, could provide more recharge to the spoils. This would shorten the time required to leach out the soluble salts. However, it would also increase the discharge of elevated TDS water to nearby springs and streams.

The Buffalo Jump mine site is also located in the recharge area for the regional groundwater flow system. Degradation of recharge water with mine spoil leachate could effect the quality of the lower flow system if sufficient downward leachage occurred beneath the mine site.

INDIAN COULEE MINE SITE

Pre-Mining

The model represents the groundwater movement in the sandstone and coal seams beneath the unsaturated mineable Rosebud and McKay coal seams. Groundwater movement in the composite system is from the northwest to the southeast discharging into the alluvium and Rosebud Creek. Natural groundwater flow conditions and corresponding average TDS water quality data are presented in Figure 8.11. Groundwater movement through the composite aquifer and discharge to the alluvial material is 240 m^3/d (848 ft^3/d). The unconsolidated material receives approximately 650.0 m^3/d (2,295 ft^3/d) of recharge over the alluvial area, yielding a total outflow of 674.0 m^3/d (2,380 ft^3/d).

Post-Mining Impacts

Most of the mineable coal is above the shallow flow system, so that only recharge water is able to leach the new mine spoils. When mining is completed, spoil material is backfilled to an approximate depth of 30.5 m (100 ft) in

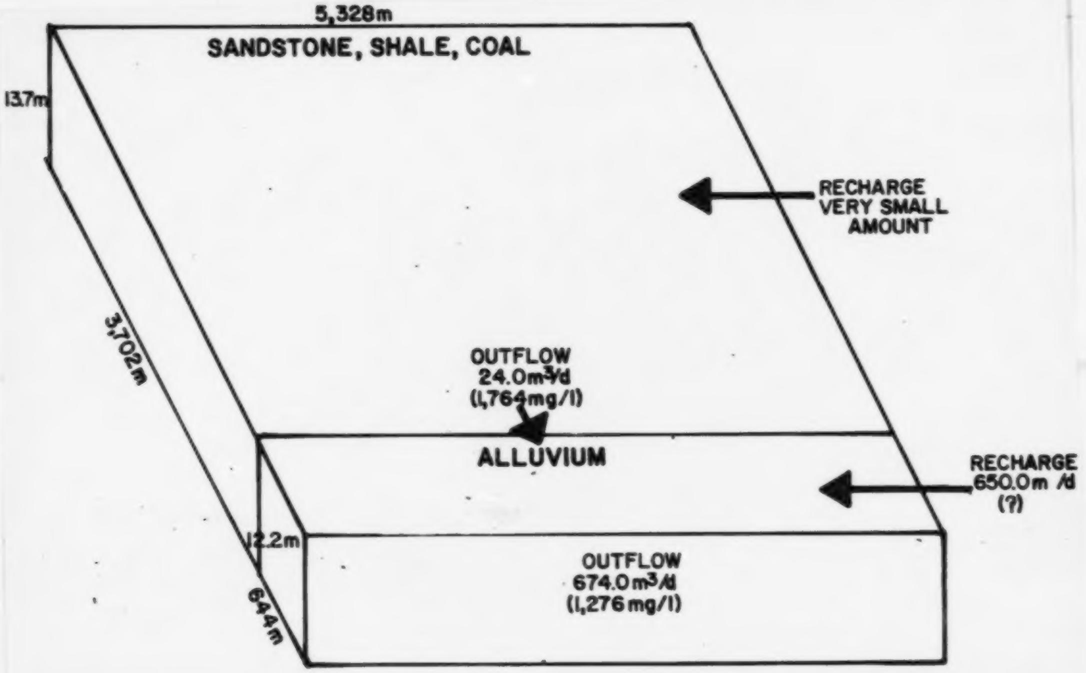

5,328m
SANDSTONE, SHALE, COAL
13.7m
RECHARGE
VERY SMALL
AMOUNT
3,702m
OUTFLOW
24.0m³/d
(1,764mg/l)
ALLUVIUM
RECHARGE
650.0m /d
(?)
12.2m
OUTFLOW
674.0m³/d
(1,276mg/l)
644m

Figure 8.11. Pre-mining Indian Coulee mine site groundwater system.

the mine pit. It is assumed that the only significant change following mining is the creation of a large surface area of spoils, which will receive recharge. It is assumed that the hydrologic characteristics of the spoils will be similar to the pre-mining conditions. Post-mining recharge rates of 0.0031 to 0.031 m/y were assumed for the spoil. The post-mining material balance model is presented in Figure 8.12. The parameters used in the model are listed in Table 8.6. The post-mining outflow from the mine site increases from the pre-mining rate of 24.0 m^3/d (848 ft^3/d) to a value of 38.6 to 169.7 m^3/d (1,363 to 5,993 ft^3/d) depending on the recharge rate. Outflow from the alluvium to Rosebud Creek increases from a pre-mining value of 674.0 m^3/d (23,802 ft^3/d) to a value from 712.6 to 843.7 m^3/d (25,165 to 29,794 ft^3/d. The resulting quality of the alluvium outflow changes from the pre-mining TDS of 1,276 mg/l to between 1,279 to 1,406 mg/l based on varying recharge rates. Post- mining surface water quality relationships are also altered. TDS impacts to Rosebud Creek at the downstream boundary of the study area and to the groundwater discharging to Rosebud Creek are listed in Table 8.7.

TABLE 8.6. PARAMETERS USED IN THE MATERIAL BALANCE MODEL OF THE INDIAN COULEE MINE SITE

PARAMETER	VALUE
STREAM$_F$	
Average flow	6.79×10^4 m^3/day
Low flow	3.32×10^4 m^3/day
STREAM$_{NTDS}$	
At average flow	662 mg/l
At low flow	776 mg/l
GW$_D$	674 m^3/day
GW$_{NTDS}$	1276 mg/l
OTHER$_R$	650 m^3/day
OTHER$_{TDS}$*	1258 mg/l
COAL$_I$	24.0 m^3/day
COAL$_{TDS}$	1764 mg/l
SPOIL$_R$	14.6 - 146 m^3/day
SPOIL$_{TDS}$**	2000 mg/l

* Calculated using equation 2.

** Based on drill cuttings from NCRP wells 18, 36A & 40A.

Analyses of water quality data indicate a single mine in the Indian Coulee area will have a measurable impact on the local groundwater quality and a minimal impact on the water quality of Rosebud Creek. In both cases, however, these impacts will not be short lived. The time it would take to pass one pore volume through the 30.5 m (100 ft) of spoils using a porosity of 0.1 would range from 100 to 1,000 years. Once the spoil recharge water reached the mine alluvium boundary, it would take approximately 20.7 years to reach Rosebud Creek, under existing gradients using the calculated hydraulic conductivity for alluvium and with an effective porosity of 0.12. Though leachate will reach the alluvium and Rosebud Creek in a relatively short time after reestablishment of groundwater flow, leaching will probably continue for hundreds of years.

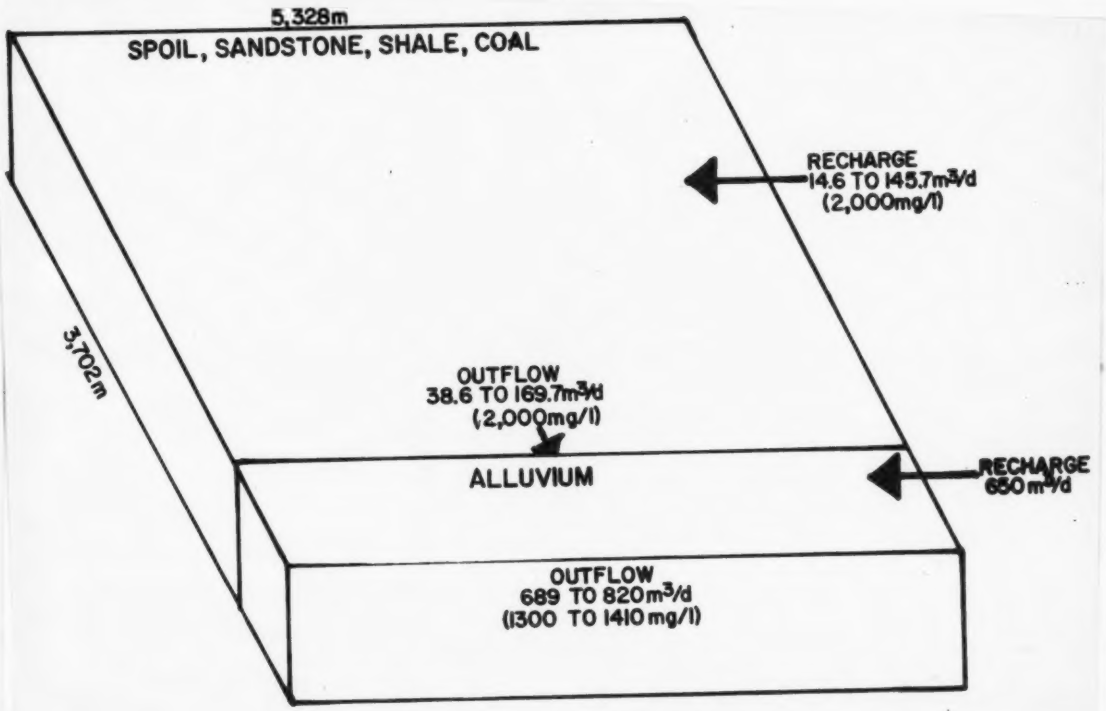

5,328m
SPOIL, SANDSTONE, SHALE, COAL
RECHARGE
14.6 TO 145.7m³/d
(2,000mg/l)
3,702m
OUTFLOW
38.6 TO 169.7m³/d
(2,000mg/l)
ALLUVIUM
RECHARGE
650 m³/d
OUTFLOW
689 TO 820m³/d
(1300 TO 1410 mg/l)

Figure 8.12. Post-mining Indian Coulee mine site groundwater system.

TABLE 8.7. IMPACTS OF THE HYPOTHETICAL INDIAN COULEE MINE ON WATER QUALITY OF ROSEBUD CREEK AND ON QUALITY OF GROUNDWATER DISCHARGING TO ROSEBUD CREEK

		Post-Mining TDS	
	Natural TDS	0.0031 m/y Recharge	0.031 m/y Recharge
Discharging Groundwater TDS (mg/l)	1276		
Streamflow TDS (mg/l) at:			
Mean Annual Flow	662	668	671
Low Flow	776	787	791

REGIONAL IMPACTS

The extensive coal deposits found in the Tongue River Valley on and around the Reservation could support large scale mining operations in the near future. Is is estimated that 4.3 billion metric tons (4.4 billion short tons) of low sulfur strippable coal lie in the Tongue River Valley on and adjacent to the Reservation. Mining operations similar to the hypothetical Logging Creek mine could exist for 20 to 40 km on either side of the river in this region (Figure 8.13).

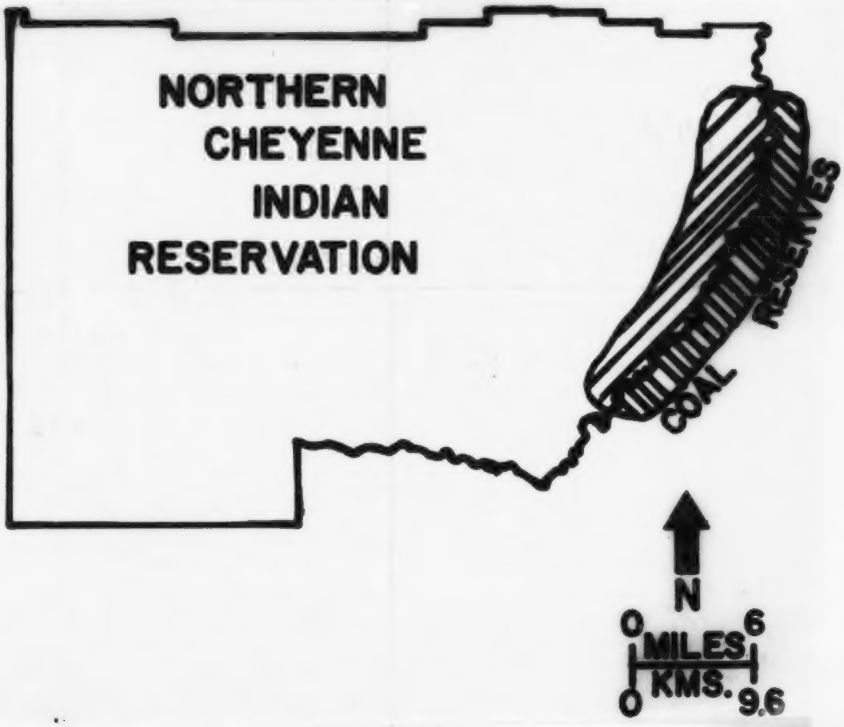


Figure 8.13. Area in Tongue River Valley selected for regional impact analysis.

Mining of this portion of the valley would create spoil water of low quality as predicted at the Logging Creek mine site. Most of the shallow groundwater in the mined area, plus parts of the down gradient regions, are of marginal use for stock and are unacceptable for other uses. Sub-irrigated crops in the alluvial valley may suffer if TDS rises above predicted levels. The quality of the Tongue River would also be affected if a large portion of the Tongue River Valley were mined.

Stream impact analyses for a 30 km section of the valley was initiated at a point 20 km upstream from the Logging Creek mine site. It was assumed that both sides of the river valley were mined. Although the thickness and extent of the coal varies widely in the valley, post-mining groundwater discharge rates were based on pre-mining Logging Creek area coal seam and alluvial flow rates, recharge data, and recharge rates to the spoil of 0.0031 and 0.031 m/y. Based on the two recharge rates, groundwater discharge to the Tongue River was calculated to be 2.1×10^4 and 2.6×10^4 $m^3/day^{-1} km^{-1}$ with TDS values of 1442 and 1986 mg/l, respectively. Calculated quality impacts to the Tongue River at the downstream boundary of the 30 km section are listed in Table 8.8.

TABLE 8.8. REGIONAL TDS IMPACTS ON THE TONGUE RIVER

Predicted TDS concentrations in the Tongue River at the northern Reservation boundary if the 30-km section of the Tongue River Valley on and adjacent to the Northern Cheyenne Reservation is mined.

	Natural TDS (mg/l)	Post-mining TDS (mg/l)	
		0.0031 m/yr Recharge	0.031 m/yr Recharge
Tongue River Flow			
Mean Annual Flow	284	301	349
50 Percentile Flow	644	683	788
Measured Low Flow	875	995	1,278

Extensive mining adjacent to the Tongue River will cause a significant change in the water quality of the river. However, calculated changes in water quality are not great enough to render the water unfit for livestock watering or irrigation. If the changes calculated for mining the area adjacent to the Reservation are coupled to changes that will be occurring upstream on the Tongue River due to strip mining, the conclusion is that water quality in the river could be severely degraded in the long term. Presently, 60 km upstream from the southern Reservation boundary, near Decker, Montana, over 18×10^6 t is being mined annually from pits located adjacent to the river. This rate could double within the next decade. Adding the impacts likely to be caused by these mining activities, the calculated TDS changes for the Tongue River double from those shown in Table 8.8. Exacerbating these calculated changes in water quality is the increasing use of Tongue River water for irrigation upstream in Wyoming. This will further degrade the quality of water in the Tongue River.

Strip mining in the Tongue River Valley will necessarily imply a long-term degradation of water quality in the Tongue River. The changes will not occur rapidly, but will happen gradually over a period of many years.

CONCLUSION

Strip mining in the Northern Great Plains Region will have a long-term impact on groundwater and surface-water quality. Evaluation of the hypothetical 9×10^6 t/yr mine in the Tongue River Valley leads to the conclusion that the impacts of a single mine on groundwater quality are significant, while the impacts on surface-water quality are small. The cumulative impact from the extensive mining which is likely to occur in the Tongue River Valley will be, though, a significant deterioration in surface-water quality in the long term. This deterioration will last for centuries.

The material-balance approach, which is based on an assumed relation between saturation paste extracts and spoil water quality, is simplistic. However, it is the only viable approach available at this time for quantifying site-specific and regional long-term impacts from coal strip mining. Process oriented deterministic models of the chemical processes occurring in the spoils and downgradient from the spoils, of recharge to the spoils, and of water movement through spoils are needed to further refine the impacts of mining. Future studies of coal strip mining should concentrate on these areas of research.

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CHAPTER A-1

CENOZOIC GEOLOGIC HISTORY OF THE NORTHERN POWDER RIVER BASIN

INTRODUCTION

The story of how the land surface now present on the Reservation came to be is a jigsaw puzzle with many missing pieces. The following reconstruction will present existing historical evidence and attempt to interconnect the evidence in a meaningful fashion. This history summarizes previously discussed information and relies on Alden (1932), Brown (1952), Lewis and Roberts (1977), and Thom et al. (1935) for many of its statements.

TERTIARY DEPOSITIONAL EVENTS IN THE NORTHERN POWDER RIVER BASIN

Any discussion of geomorphic events should take into consideration the origin of rock formations exposed on the Reservation, as well as those which may have been eroded away but remnants of which are preserved elsewhere in the area.

All Tertiary rocks in southeastern Montana are of fluvial, lacustrine or other continental origin. There are no marine deposits. The last retreat of a marine seaway from southeastern Montana was in late Cretaceous time and is represented by the Fox Hills sandstone. A broad regional uplift in central Montana then occurred and marked the beginning of the Laramide Orogeny which reached its peak in early Eocene time. During this period the Powder River Basin began to form and sediments were shed into its northern part from the west to northwest. The climate was warm and moist during the Paleocene and early Eocene Epochs. East to southwest trending rivers in the early Paleocene deposited sand and clay which today forms the Tullock Member of the Fort Union Formation. As the Cannonball Sea made its appearance in North Dakota, the shoreline to the west receded somewhat and the Lebo Shale was deposited in a quieter outer delta, through still continental environment. The Lebo reached its greatest thickness in Wyoming. Increased uplift in the late Paleocene brought a return to more active fluvial environments. Sands, silts, clays, and peats of the Tongue River Member were laid down by an east-to-southeast flowing river system which prograded over the Lebo Shale, depositing more sediment to the east than to the south. Peat was deposited in flood basin swamps in back of river levees and in abandoned lobes of delta systems. These peats accumulated to great thicknesses and today form extensive beds of coal. Channel sands formed lenticular sandstone bodies which today snake through the finer-grained strata.

The early Eocene was a time of maximum relief, when much sediment was shed into the Powder River Basin. Strata in the basin were strongly folded and faulted to near their present structure; the Bighorn Mountains were raised along range-front faults and coarse alluvial-fan conglomerates and sands were shed into the developing southern Powder River Basin, where an unconformable contact is now exposed between the Eocene Wasatch Formation and the Paleocene Fort Union Formation. In southeastern Montana, the contact is conformable and the two formations are fairly similar in composition and origin. Uplift was renewed in the Black Hills in late Eocene time and the basin was tilted westward.

By early Oligocene time tectonic activity had largely ceased in the area. The mountain ranges were being stripped and their fragments deposited by river systems onto the plains of eastern Montana. Volcanic activity in the Absaroka Highlands to the west and possibly the Bear Lodge-Devil's Tower igneous bodies to the east buried much of the area in ash. General relief slowly decreased during Oligocene and Miocene time. Tertiary formations such as the Oligocene silts and volcanic tuffs of the White River Formation and the Miocene sandstones, tuffs, and conglomerates of the Arikaree Formation covered much of southeastern Montana, spreading out over the land surface and filling stream channels cut into an older topography.

Alden (1932) hypothesized that the main river of Oligocene or Miocene time may have flowed in a gravel-floored valley 16 to 32 km (10 to 20 mi) wide south of the line of the present Yellowstone Valley between Billings and Miles City. As the Yellowstone cut down, moving toward the north, streams such as the Tongue River and Rosebud Creek extended themselves northward.

Tertiary formations including the Wasatch, White River and Arikaree very likely once covered the Reservation area before being eroded away.

The continual erosion of sediments from the highlands of the Bighorn Mountains and Black Hills into the Powder River Basin and the plains to the northeast in Montana reduced the mountain areas in Miocene and Pliocene time almost to a peneplain or pediplain surface consisting of low ranges swamped in their own alluvial debris (as evidenced by the Miocene gravels on the Subsummit Plateau 610 meters (2,000 feet) below the crest of the Big Horn Range (Thornbury, 1969, p. 284; Hoppin and Jennings, 1971, p. 44)).

However, during the late Pliocene, major mountain ranges were exhumed, including the Big Horns. The cause may have been regional uplift (Thom *et al.*, 1935), selective uplift along faults at the mountain front (Hoppin and Jennings, 1971, p. 44), normal faulting associated with a regional uplift (Lewis and Roberts, 1978), or as seemingly insignificant a factor as increased erosion of the plains due to increased rainfall. Perhaps all these factors had a part. In any case, the gentle topography of Wyoming and southeastern Montana as evidenced by the Divide Highland began to be dissected. Approximately 80 to 100 kilometers (50 to 62 miles) west of the Northern Cheyenne Reservation, the Big Horn River superimposed itself directly across the Big Horn Range and carved the spectacular Big Horn Canyon (Clark and Stearn, 1969, p. 260).

As base level began to be lowered, the present cycle of downcutting in the sedimentary rocks of the Northern Powder River Basin was initiated.

Pleistocene glacially-induced events such as the change of the Missouri River drainage from north into Hudson Bay to east into the Mississippi River system may also have contributed to base level lowering (Alden, 1932).

RECONSTRUCTION OF PLIO-PLEISTOCENE EVENTS

During the course of field work, several geologic observations were made which could provide clues to the geomorphic history of the Reservation and vicinity. These observations include the following:

1) The course of Rosebud Creek makes a sharp bend from north to east-northeast near the town of Busby. West of Busby a gap has formed between the Wolf Mountains to the south and the Little Wolf Mountains to the north;

2) Valley and terrace alluvium of Rosebud Creek northeast of Busby contains rounded gravels of quartzite and other igneous and metamorphic rocks which do not occur as bedrock anywhere in the present drainage of Rosebud Creek.

A sequence of topographic reconstructions from late Pliocene to the present is presented on the following pages. On the basis of existing topographic and geological information, it is hypothesized that the Tongue River has "pirated" drainage tributaries from the ancestral Rosebud Creek and that Rosebud Creek once extended into the Big Horn Mountains. Moreover, at an earlier time Rosebud Creek may have flowed through the gap between the Wolf and Little Wolf Mountains west of Busby. Rosebud Creek's present course south of Busby could have been tributary to the main stream draining the Big Horn or Absaroka Mountains west of the Wolf Mountains. This tributary may have evolved into the main stream when the Little Big Horn River captured the former upper drainage of Rosebud Creek. A broad synclinal trough which currently extends near and parallel to the axis of the Tongue River in the Northern Powder River Basin is proposed to have been reactivated in late Pliocene or early Pleistocene time and to have contributed to the diversion of the Rosebud Creek headwaters by the Tongue River. Late Pliocene to Pleistocene downwarping is supported by three sources:

> 1) Bass (1932, p. 48) states: "The occurrence of stream gravel confined almost wholly to the west sides of the stream courses (in the Ashland Coal Field) probably indicates that the region has been tilted eastward subsequent to and perhaps during the deposition of the gravel beds in Pleistocene time." Pierce (1936) concurs in this judgement. In addition, the long, semi-parallel networks of tributaries flowing east to southeast on the northwest side of Rosebud Creek and the Tongue River are not duplicated on the southeast side. Instead, less linear and relatively short stream courses are found with the exception of major tributaries such as Muddy Creek in the Rosebud drainage, and O'Dell Creek and Hanging Woman Creek in the Tongue River drainage. As the region tilts to the east, Tongue River and Rosebud Creek may also be shifting slowly eastward. As a result, tributaries to the west of the rivers extend themselves eastward, while tributaries to the east are continually being cut back by the eastward shift of the major rivers.

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In addition, the mouths of the tributary drainages to the west of the Tongue River have generally well-defined channels. The mouths of the tributaries to the east are less defined. This may indicate more subsidence to the east of the river than to the west and reflect the tilting.

2) The Lake Basin and Nye-Bowler structural lineaments, considered to have formed in late Pliocene time (Lewis and Roberts, 1978) consist of east-west trending zones of en echelon faulting in a NE-SW direction. Tensional features between these two systems may account for either normal faulting or subsidence in a NE-SW direction. It is interesting to note that the axis of the Powder River Basin shifts to the northeast, along which the Tongue River trends, at about the horizon of the Nye-Bowler Lineament near Decker, Montana. If one traces a line eastward from the Lake Basin Lineament, it intersects the Tongue River approximately at the northern edge of the Reservation. The Tongue River turns back northward again at this point.

3) The southeastward tilting ancient erosional surface reported by Thom et al. (1935) and Baker (1929) to form the eastern slopes of the Rosebud (Wolf) Mountains and the highlands west of the Tongue River is in contrast with the current northward trend of the Tongue River and argues for deformation after the erosional surface was established. Baker (1929) also believed that Rosebud Creek has captured the headwaters of Leaf Rock Creek, a tributary of the Tongue River. Due to the greater gradient of Rosebud Creek versus the Tongue River, he suggested that Rosebud Creek was cutting more actively. However, Leaf Rock Creek has northwest-southeast trend and the headwaters of Rosebud Creek trend east-west. This seems to suggest to Project staff that the relation is the other way around, and Leaf Rock Creek is about to capture the headwaters of Rosebud Creek.

STAGE 1 - MIDDLE PLIOCENE - 5,000,000 YEARS AGO

This was a period of low relief when the mountains were swamped in their own alluvial debris. Meandering rivers emanated from the low Big Horn Hills which rose not more than 610 meters (2,000 feet) above the surrounding gently rolling plains. The Tongue River Member of the Fort Union Formation was covered in many places by more recent formations such as the White River and Arikaree, and possibly younger gravel terraces laid down by the meandering rivers (Figure A-1).

The main drainage system was the Rosebud River, which split into two branches near the present site of Busby, Montana - one branch going southwest between a low range of hills which began tilting up as a syncline was developing in the east. Little Bighorn Creek had not yet captured the headwaters of the West Rosebud River extending into the Bighorn Hills. East Rosebud River, the other branch, extended into the headwaters of the present-day Tongue River and brought gravels such as are now present in the Divide Highland down from the Big Horns. The present-day Tongue River was a small creek.

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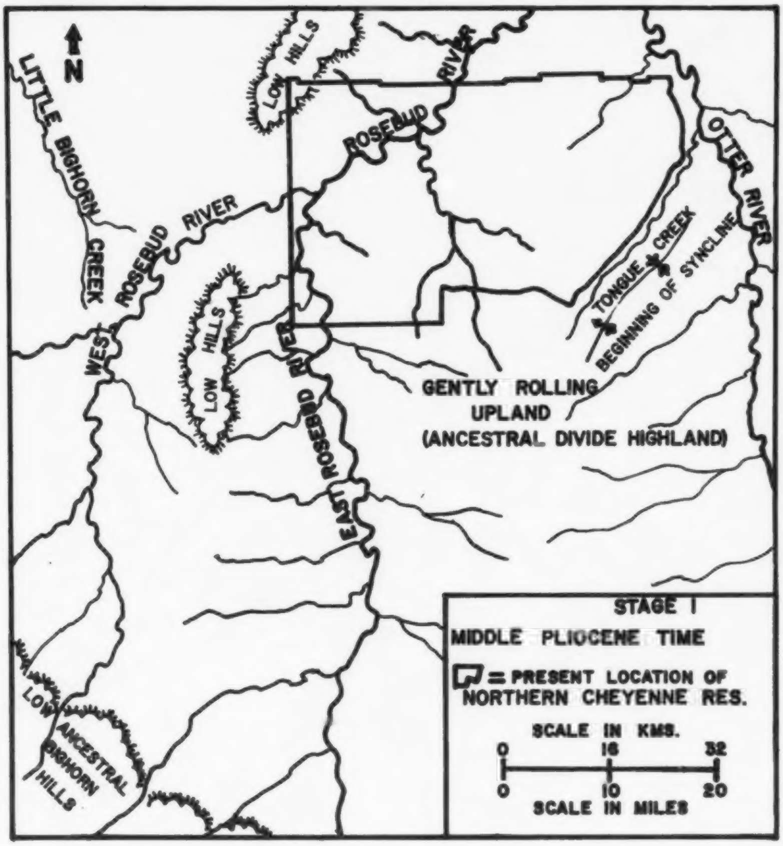
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BEGINNING OF SYNCLINE
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STAGE I
MIDDLE PLIOCENE TIME
= PRESENT LOCATION OF
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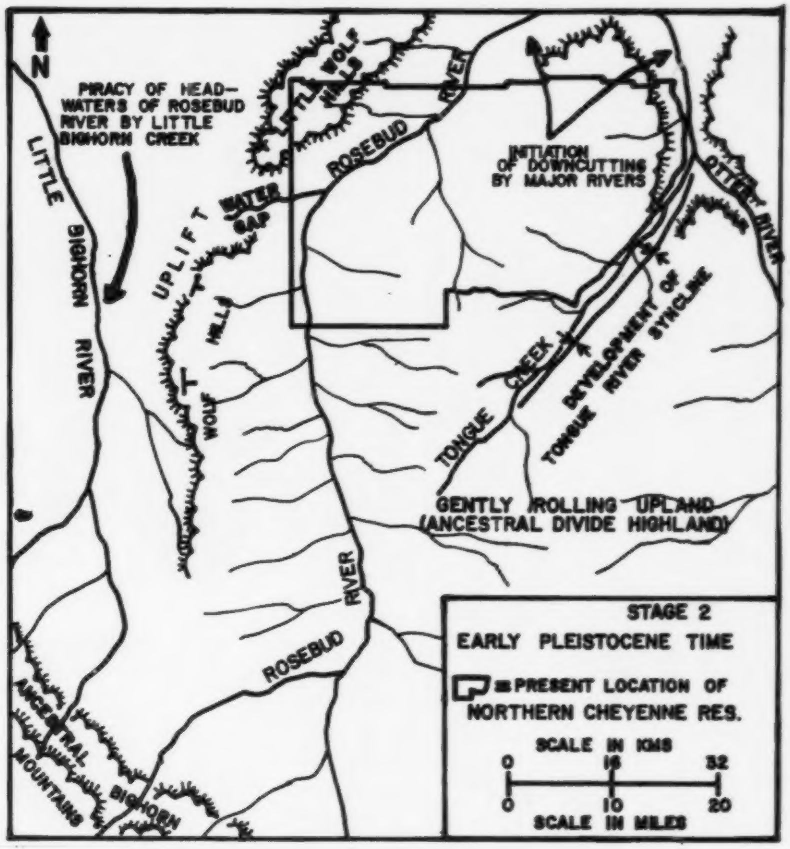
Figure A-1. Geomorphic development, southeastern Montana - middle Pliocene time.

Another possibility is that gravel terraces on the Divide Highlands were laid down by rivers coming from the west, and not the ancestral Tongue River. The volcanic terrain of the Absaroka Mountains could account for the large percentage of andesitic cobbles in the gravels.

STAGE 2 - EARLY PLESITOCENE - 2,000,000 YEARS AGO

As uplift and/or increased rainfall commenced in late Pleistocene time, the Big Horn Mountains began to be exhumed. Base level was lowered in the plains to the east and major river systems began cutting down into the former gently rolling surface. As the rivers cut through the White River and Arikaree Formations into the Fort Union Formation, the uppermost coal seams of the Tongue River Member were exposed and began burning to clinker (Figure A-2).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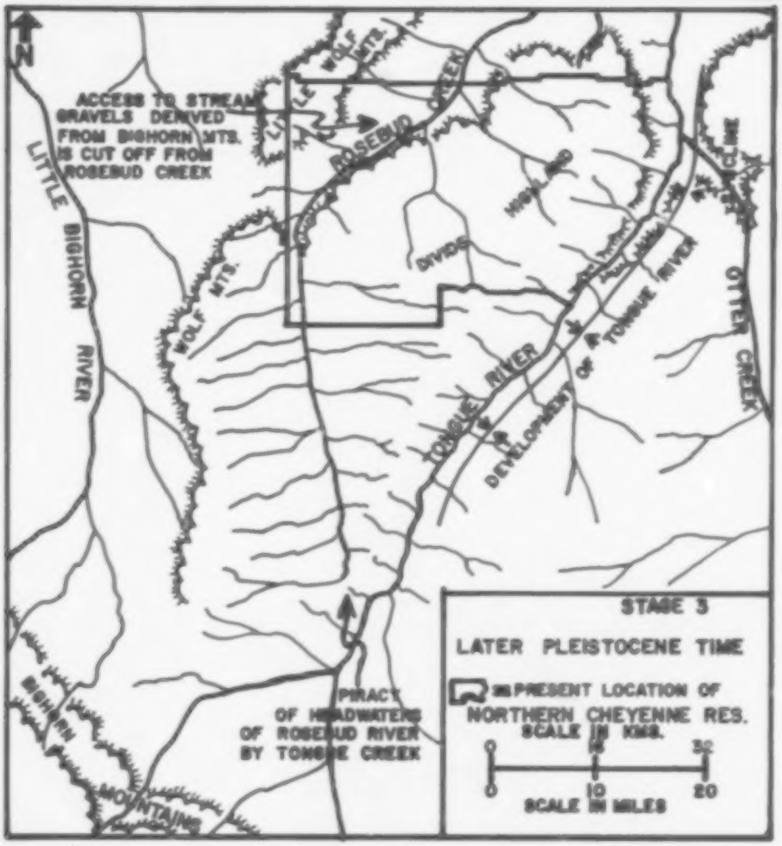
TONGUE CREEK
DEVELOPMENT OF TONGUE RIVER SYNCLINE
GENTLY ROLLING UPLAND (ANCESTRAL DIVIDE HIGHLAND)
RIVER
ROSEBUD
ANCESTRAL MOUNTAINS
BIGHORN
STAGE 2
EARLY PLEISTOCENE TIME
= PRESENT LOCATION OF NORTHERN CHEYENNE RES.
SCALE IN KMS
0
16
32
0
10
20
SCALE IN MILES

Figure A-2. Geomorphic development, southeastern Montana - early Pleistocene time.

A northeast-trending syncline continued developing along the present course of the Tongue River in southeastern Montana, tilting surfaces upward to the east and west. Tongue Creek began extending itself southwestward along the course of this syncline. On the west limb of the syncline, the Wolf Hills were uplifted, causing Little Bighorn Creek to capture the headwaters of West Rosebud River. East Rosebud River still had its headwaters in the Big Horn Mountains.

STAGE 3 - LATER PLEISTOCENE - 300,000 YEARS AGO

Uplift, erosion, and uncovering of the Big Horn Mountains and plains to the northeast had proceeded to the point where most of the White River and Arikaree Formations had eroded away, while the Wasatch Formation and Tongue River Member were actively being cut into by the major river systems. Fine sediments were washed out of Pliocene stream deposits, leaving coarse gravels stranded on the Divide Highland. Burning of coal seams became more extensive (Figure A-3).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DEVELOPMENT OF A TONGUE RIVER
OTTER CREEK
BIGHORN MOUNTAINS
PIRACY OF HEADWATERS OF ROSEBUD RIVER BY TONGUE CREEK
STAGE 3
LATER PLEISTOCENE TIME
PRESENT LOCATION OF NORTHERN CHEYENNE RES.
SCALE IN KMS.
0
16
32
0
10
20
SCALE IN MILES

Figure A-3. Geomorphic development, southeastern Montana - later Pleistocene time.

The Tongue River syncline had developed to the point where the surface had warped down until it was lower than the bed of Rosebud River, and Tongue Creek worked its way southwestward along the axis of the syncline until it captured the headwaters of Rosebud River. The northwest-southeast trending tributaries of the fledgling Tongue River worked their way into the highland surfaces and began to capture the east-west trending tributaries of Rosebud Creek, south of present-day Busby. As a result, the flow of Rosebud Creek was greatly reduced, and access to stream gravels derived from the Big Horn Mountains was cut off.

STAGE 4 - PRESENT

The present-day topographic setting is a dissected plateau surface bounded by the Big Horn Mountains to the west. The Little Big Horn River has cut down

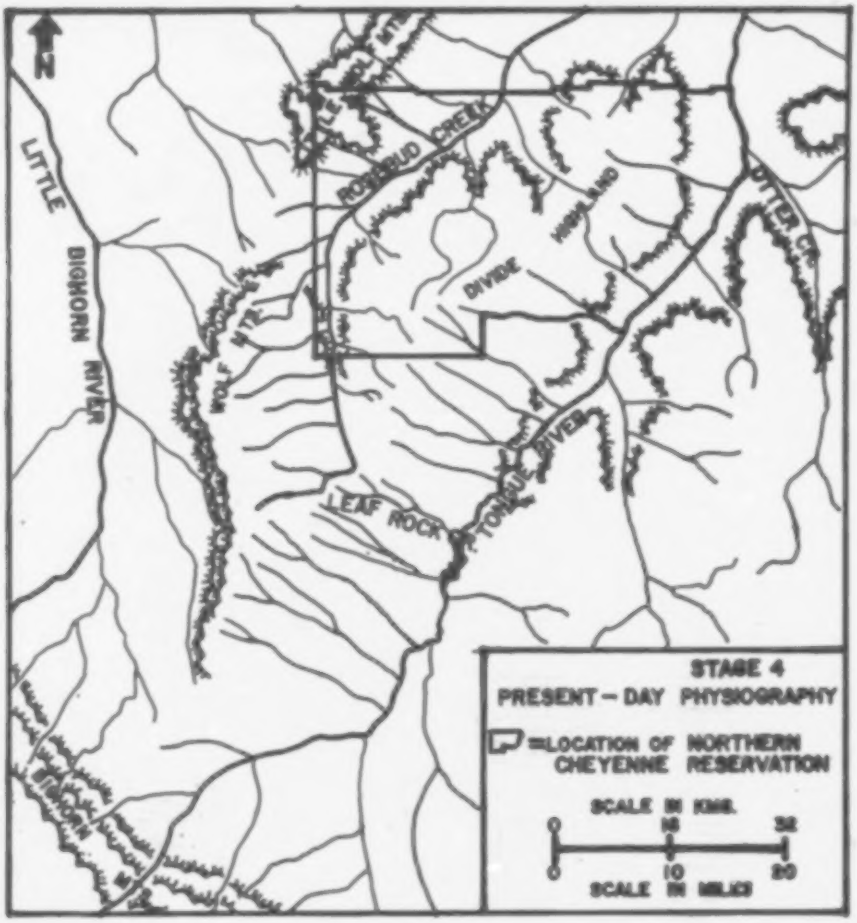

N
LITTLE BIGHORN RIVER
LITTLE WOLF MTS
ROSEBUD CREEK
WOLF MTS
HIGHLAND
DIVIDE
OTTER CR.
TONGUE RIVER
LEAF ROCK
BIGHORN MTS
STAGE 4
PRESENT-DAY PHYSIOGRAPHY
=LOCATION OF NORTHERN CHEYENNE RESERVATION
SCALE IN KMS.
0
16
32
0
10
20
SCALE IN MILES

Figure A-4. Geomorphic development, southeastern Montana - present-day physiography.

through the Fort Union Formation into Cretaceous sediments. Eastward from the Wolf Mountains the Fort Union still covers the surface. The Wasatch Formation is limited to the south of the diagram near the Wyoming border. Tongue River and Rosebud Creek have cut up to 460 meters (1,500 feet) into the Pliocene surface of the Divide Highland. As their tributaries work their way back into the highlands, coal seams continue to be exposed and burnt. The major valleys contain up to 37 meters (120 feet) of Pleistocene alluvial fill that may have been deposited as base level rose after glacial periods (which scoured the valleys out) ended (Figure A-4).

The northwest-trending tributaries of the Tongue River continue pirating the headwaters of Rosebud Creek. Even now, Leaf Rock Creek, which flows southeast into the Tongue River, is about to capture the west-trending headwaters of Rosebud Creek above its Big Bend. In the area of the diagram, Rosebud Creek lies a few hundred meters (several hundred feet) above elevation of the Tongue River. As long as this situation remains in effect, Rosebud Creek will be whittled down by the tributaries of the Tongue River. In the future, the Divide Highland will be worn down by Rosebud Creek and the Tongue River. The Little Wolf Mountains will be worn down by Rosebud Creek, Tullock Creek, and Sarpy Creek; and the Wolf Mountains will be worn down by Tongue River, Little Bighorn River, and Rosebud Creek.

CHAPTER A-2

DEPOSITIONAL ENVIRONMENT OF THE TONGUE RIVER MEMBER

The Tongue River Member formed in a series of fluvial to lacustrine environments associated with development of a delta-front system prograding generally to the east. As rivers meandered over a low plain, shifting of delta lobes, variations in sediment influx, climatic fluctuations and flooding resulted in semi-cyclic deposition. Abundant peaty material accumulated in back swamps associated with topographic lows between river channel levees and along delta plains between distributary channels. Peat also filled abandoned oxbow lakes.

Four distinct depositional environments (Moran and Cherry, 1977, pp. 3-5) were created in this system.

1) River channel areas produced medium to very fine sand, generally oxidized to some degree, and commonly massive;

2) Upper levee environments contained thick beds of coarse to medium silt with interbeds of poorly sorted fine-grained sand;

3) Lower levee environments contained fine-grained silt with interbeds of coarse silt and clay, and thick and abundant peat zones. These peats accumulated in poorly-drained backswamp areas where reducing conditions were present. Well-drained backswamps, between the peaty zones and higher parts of the levee, were exposed to air for long enough periods that the organics were able to oxidize and soils with kaolinitic clay (underclay) were formed (Land and Weimer, 1978). Calcareous material was concentrated in very fine sand and silt sizes and deposited most commonly in levee environments;

4) Flood basin environments were characterized by thinly bedded dark gray clay and medium to fine grained silt, with thin beds of peat and carbonaceous clay. These areas often contained water too deep for swamp plants to grow.

During floods, rivers would overflow their levees and would send mud and sand into the back swamp, creating a crevasse splay deposit. If a gap in the levee were large enough, the river would form a new channel through the gap and abandon the old one, which would then slowly subside and collect large thicknesses of peat. The situation can be likened to the present day swamps along the lower Mississippi River. In its backswamps and abandoned delta lobes, such as the Atchafalaya Basin, massive peat layers are accumulating today (Weimer, 1977, pp. 135). Figure A-5 (after Weimer 1973) and Figure 5.11 from Frazier and Ozanik (1969) graphically illustrate this process of deposition.

Gray shale found at the base of most coal seams on the Reservation was usually formed in a well-drained swamp. As a delta lobe was abandoned and the former levee system subsided, water level rose, and the former well-drained swamp became a poorly-drained swamp, causing peat to prograde over large areas (Weimer, 1977).

Bryson and Bass (1973), working in the Tongue River Member in the vicinity of Moorhead, southeastern Montana, recognized a cyclic unit consisting of a basal, massive, faintly cross-bedded sandstone, a thin shale and claystone layer, coal, and an upper bed dominated by shale. Matson and Pinchock (1977) state that Bryson and Bass concluded that the coal was formed in coastal swamps at varying distances from the shoreline. The basin was unstable, owing to periodic uplift of the western source. The shale overlying the coal represents either periods of subsidence that moved the shore westward or periods of accelerated deposition from a lowlying source.

Weimer (1977) states five conditions which had to be present at time of deposition to produce commercial thicknesses of coal:

1) The water had to be fresh and clear to keep the ash content and number of partings low;

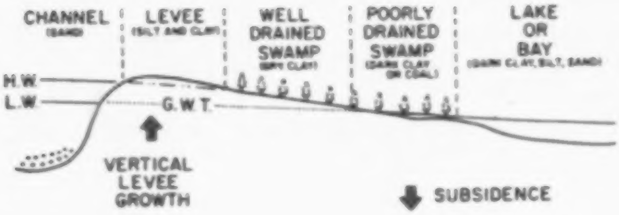
2) The organics had to come from land-derived plants:

3) The coal had to accumulate in a poorly-drained swamp with water present deep enough to keep the organics from oxidizing but not so deep as to prevent plant growth.

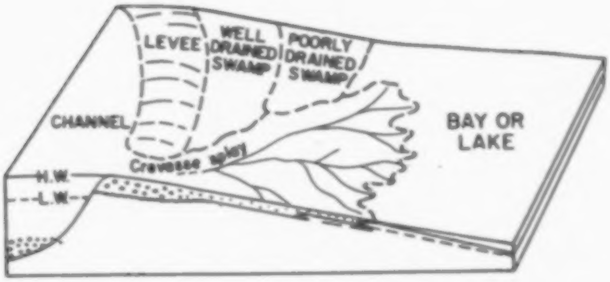
4) A moist climate favorable for production of vegetation was needed;

5) A delicate balance between rates of accumulation and rates of subsidence had to be maintained for long periods of time to keep the swamp in its productive state. Obernyer (1978) estimates that it took 100,000 to 200,000 years for the 30.5 to 61 m (100 to 200 ft) thick Lake De Smet coal in Wyoming to form, assuming .15 m (o.5 ft) of peat accumulation per century and a compaction factor of 5 m of peat to produce 1 m of coal.

Where did the sediments of the Tongue River Member come from ? The Project staff consider the Jimtown sandstone to correlate with the massive sandstone unit Bass (1932) and Dobbin (1929) mention as occurring below the Sawyer and Knobloch seams. Bass notes that this sandstone seems to extend for tens of kilometers and may be more of a sheet sandstone than a channel deposit and that its cross-strata dip to the east. As the cross-strata generally dip in the direction of sediment transport, it is logical to assume that the sediments came from the west and northwest and the rivers deposited their coarser massive sands in the western part of the area before depositing finer sediments to the east. Matson and Pinchock (1977, p. 96) concur on the basis of time-transgressive evidence that the depositional front of the Fort Union


CHANNEL
(SAND)
LEVEE
(SILT AND CLAY)
WELL DRAINED SWAMP
(DRY CLAY)
POORLY DRAINED SWAMP
(DARK CLAY OR COAL)
LAKE OR BAY
(DARK CLAY, SILT, SAND)
H.W.
L.W.
G.W.T.
VERTICAL LEVEE GROWTH
SUBSIDENCE

Environments of deposition and processes occurring in channel--channel margin areas.


LEVEE
WELL DRAINED SWAMP
POORLY DRAINED SWAMP
CHANNEL
BAY OR LAKE
Crevasse splay
H.W.
L.W.

Relationship of crevasse splay to other channel margin environments.

Figure A-5. Possible depositional models for coal-bearing strata (after Weimer, 1973).

moved in a general south and east direction. The general thickening of the Tongue River Member from the west to the east of the Reservation area (Lewis and Roberts, 1977, map) is also in accord with the concept that rivers coming from an uplift to the west associated with the Laramide period of mountain building deposited their sediment load to the east in the Powder River Basin. The sandstones and siltstones of the Tongue River Member wedge out and are replaced by the finer-grained clays and shales of the Lebo Shale Member further south and east near Gillette, Wyoming, possibly indicating a delta-front environment in that area.

CHAPTER A-3

COAL GEOLOGY STUDIES IN THE VICINITY OF THE NORTHERN CHEYENNE RESERVATION

The following maps and accompanying tables depict the extent of published coal geology field studies in the vicinity of the Northern Cheyenne Reservation by the U.S. Geological Survey and the Montana Bureau of Mines and Geology (Figures A-6 and A-7, and Tables A-1 and A-2).

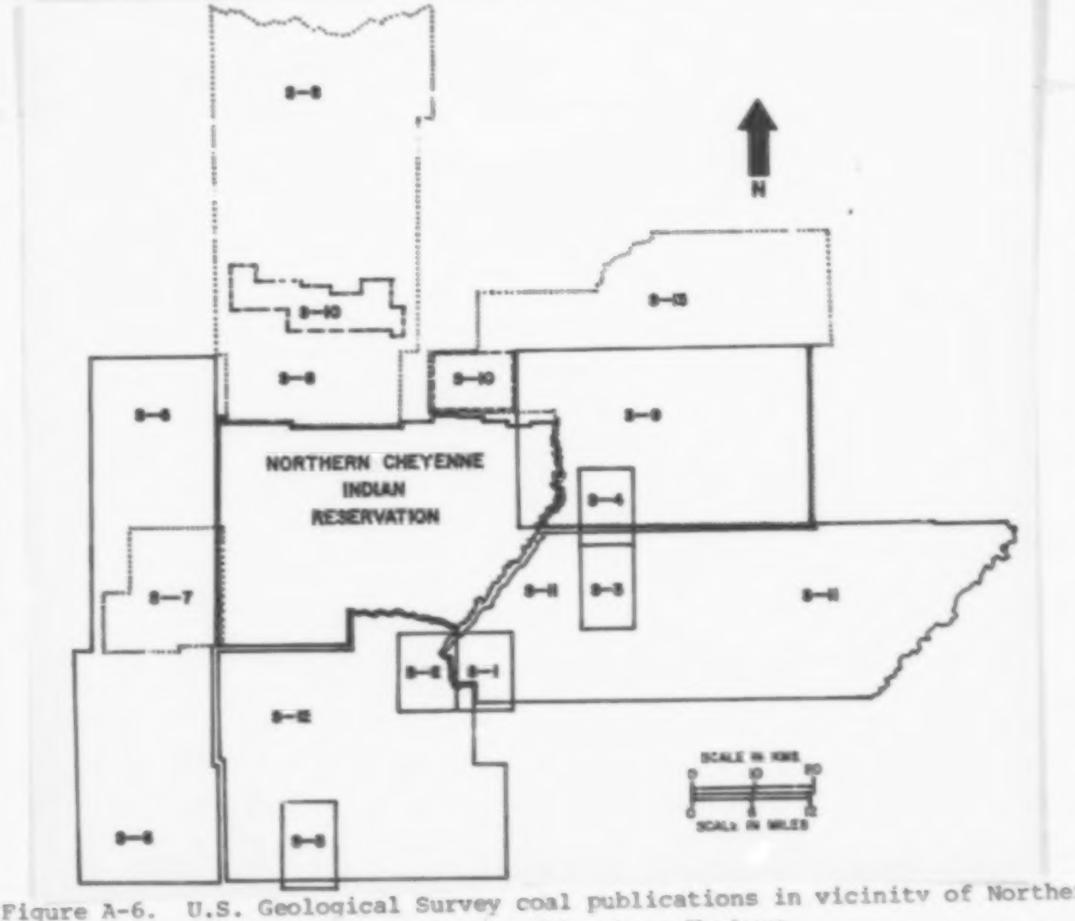

N
9—10
9—13
9—10
NORTHERN CHEYENNE
INDIAN
RESERVATION
9—4
9—7
9—11
9—3
9—11
9—2
9—1
9—12
SCALE IN KMS
0
10
20
0
6
12
SCALE IN MILES

Figure A-6. U.S. Geological Survey coal publications in vicinity of Northern Cheyenne Reservation, southeastern Montana.

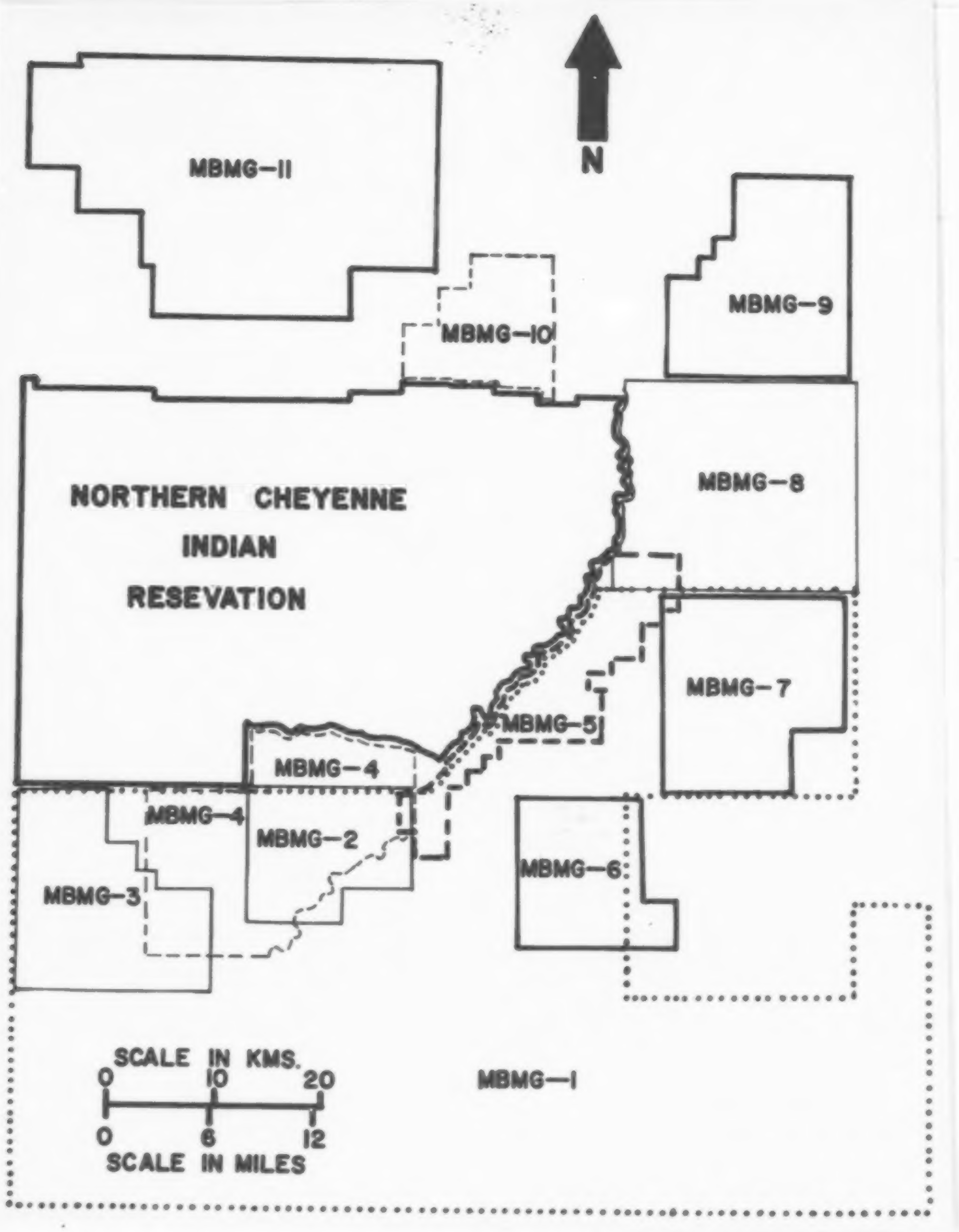

N
MBMG-11
MBMG-10
MBMG-9
MBMG-8
NORTHERN CHEYENNE
INDIAN
RESEVATION
MBMG-7
MBMG-5
MBMG-4
MBMG-4
MBMG-2
MBMG-3
MBMG-6
SCALE IN KMS.
0
10
20
0
6
12
SCALE IN MILES
MBMG-1

Figure A-7. Montana Bureau of Mines and Geology coal studies in vicinity of Northern Cheyenne Reservation, southeastern Montana.

TABLE A-1

U.S. GEOLOGICAL SURVEY COAL STUDIES ADJACENT TO NORTHERN CHEYENNE RESERVATION

S-1 Culbertson, W. C., and Klett, M. C., 1976, Geologic map and coal sections of the Browns Mountain quadrangle, Rosebud County, Montana: U.S. Geol. Surv. Misc. Field Studies Map MF-814.

S-2 Mapel, W. J., 1976, Geologic map and coal sections of the Birney quadrangle, Rosebud County, Montana: U.S. Geol. Surv. Misc. Field Studies Map MF-813.

S-3 McKay, E. J., 1976, Preliminary geologic map and coal sections of the King Mountain quadrangle, Rosebud and Powder River Counties, Montana: U.S. Geol. Surv. Misc. Field Studies Map MF-817.

S-4 McKay, E. J., 1976, Preliminary geologic map and coal sections of the Willow Crossing qualrangle, Rosebud and Powder River Counties, Montana: U.S. Geol. Surv. Misc. Field Studies Map MF-802.

S-5 Law, B. E., and Grazis, S. L., 1972, Preliminary geologic map and coal resources of the Decker quadrangle, Big Horn County, Montana: U.S. Geol. Surv. Misc. Field Studies Open-File Rept.

S-6 Thom, W. T., Jr., Hall, G. M., Wegemann, C. H., and Moulton, C. F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana: U.S. Geol. Surv. Misc. Bull. 856.

S-7 Mapel, W. J., 1978, Preliminary Geologic Map of the Crow Reserve Area, Big Horn County, Montana: U.S. Geol. Surv. Open - File Rept. 78-998.

S- 8 Dobbin, C. E., 1930, The Forsyth Coal Field, Rosebud, Treasure, and Big Horn Counties, Montana: U.S. Geol. Surv. Bull. 812-A.

S- 9 Wegemann, C. H., 1910, Notes on the coals of the Custer National Forest, Montana: U.S. Geol. Surv. Bull. 381-A.

S-10 Kepferle, R. C., 1954, Selected deposits ofstrippable coal in central Rosebud County, Montana: U.S. Geol. Surv. Bull. 995-1.

S-11 Warren. W. C., 1959, Reconnaissance geology of the Birney Broadus coal field, Rosebud and Powder River Counties, Montana: U.S. Geol. Surv. Bull. 1072-J.

S-12 Baker, A. A., 1929, The northern extension of the Sheridan coal field, Big Horn and Rosebud Counties, Montana: U.S. Geol. Surv. Bull. 806-B.

TABLE A-1 (cont.)

S-13	Bass, N. W., 1932, The Ashland coal field, Rosebud, Powder River and Custer Counties, Montana: U.S. Ceol. Surv. Bull. 831-B.

TABLE A-2

MONTANA BUREAU OF MINES AND GEOLOGY COAL STUDIES ADJACENT TO NORTHERN CHEYENNE RESERVATION

MBMG 1

Matson, R. E., and Van Voast, W. A., 1970, Preliminary summary report of strippable low sulfur coals of southeast Montana, Part I: Mont. Bur. Mines and Geology Progress Report to HEW.

MBMG 11

Matson, R. E., and Blumer, W., 1973, Quality and reserves of strippable coal, selected deposits, southeastern Montana: Mont. Bur. Mines and Geology Bull. 91.

2 - Plate 7 - Map of Birney Coal Deposit

3 - Plate 5ABC - Maps of Kirby Coal Deposit

4 - Plate 6AB - Maps of Canyon Creek Coal Deposit

5 - Plate 11AB - Maps of Poker Jim Creek - O'Dell Creek Coal Deposit

6 - Plate 8 - Map of Poker Jim Lookout Coal Deposit

7 - Plate 12 - Map of Otter Creek Coal Deposit

8 - Plate 13AB - Maps of Ashland Coal Deposit

9 - Plate 29 - Map of Beaver Creek - Liscom Creek Coal Deposit

10 - Plate 30 - Map of Greenleaf Creek - Miller Creek Coal Deposit

11 - Plate 14 - Map of Colstrip Deposit

CHAPTER A-4

STRATIGRAPHIC LOGS

The following three lithologic logs describe results of continuous cores which were drilled in each of the priority study sites and are considered representative of the geology of the area.

Figure A-8 shows overburden and interburden characteristics and thicknesses of the main Knobloch and lower Knobloch (Nance) coal beds at NCRP Core Hole 28C in the Logging Creek Priority Study Area.

Figure A-9 describes overburden and interburden characteristics and thicknesses of the Anderson coal bed and associated benches at NCRP Core Hole 25C in the Buffalo Jump Priority Study Area.

Figure A-10 describes overburden and interburden characteristics and thicknesses of the Rosebud and McKay coal beds at NCRP Core Hole 36C in the Indian Coulee Priority Study Area.

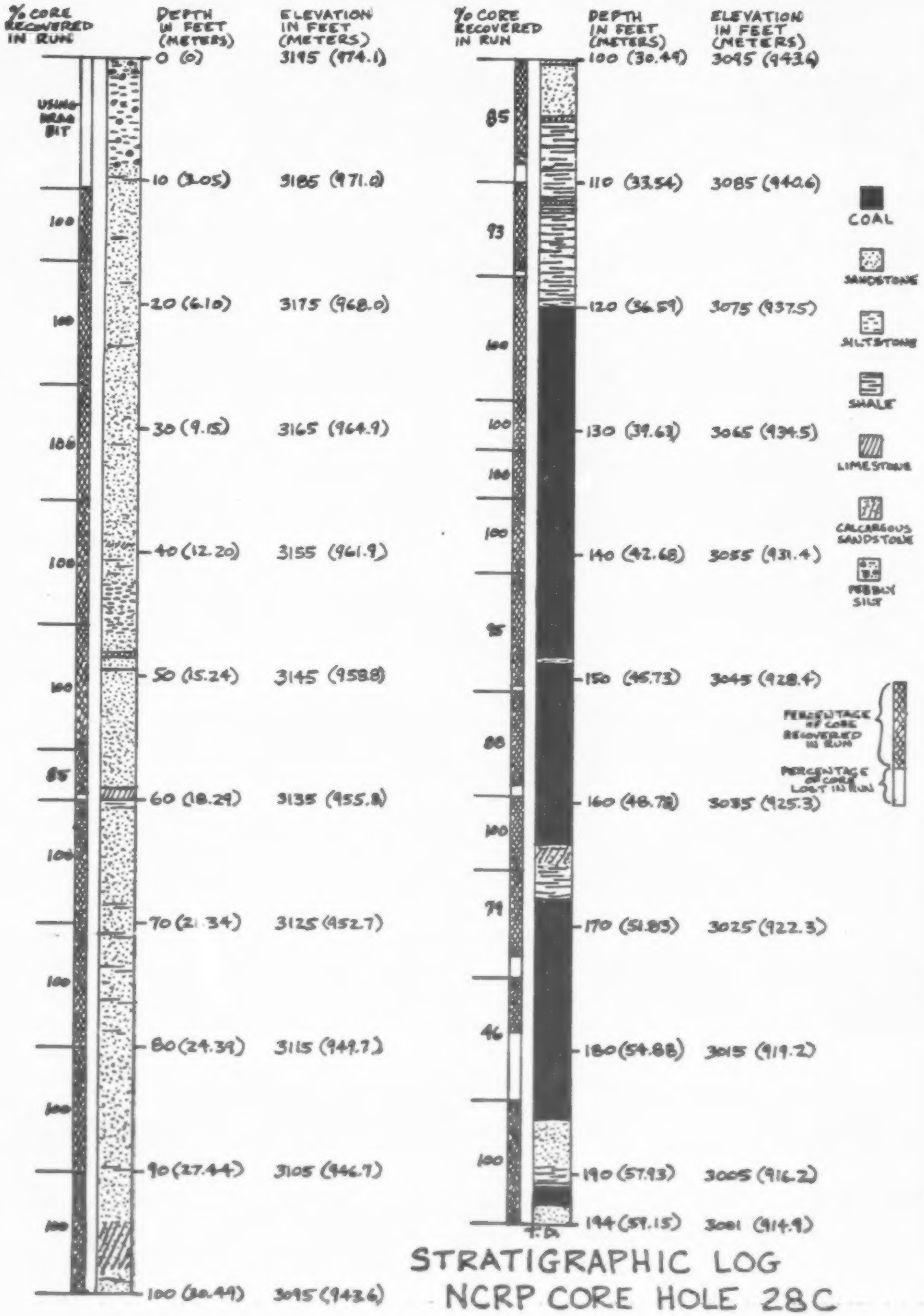

% CORE RECOVERED IN RUN
DEPTH IN FEET (METERS)
ELEVATION IN FEET (METERS)
USING DRAG BIT
0 (0)
3195 (974.1)
10 (3.05)
3185 (971.0)
20 (6.10)
3175 (968.0)
30 (9.15)
3165 (964.9)
40 (12.20)
3155 (961.9)
50 (15.24)
3145 (958.8)
60 (18.29)
3135 (955.8)
70 (21.34)
3125 (952.7)
80 (24.39)
3115 (949.7)
90 (27.44)
3105 (946.7)
100 (30.49)
3095 (943.6)
100
85
100
100
100
100
100
100
100
85
100
100
100
100
110 (33.54)
3085 (940.6)
93
120 (36.59)
3075 (937.5)
100
130 (39.63)
3065 (934.5)
100
140 (42.68)
3055 (931.4)
95
150 (45.73)
3045 (928.4)
88
160 (48.78)
3035 (925.3)
100
79
170 (51.83)
3025 (922.3)
46
180 (54.88)
3015 (919.2)
100
190 (57.93)
3005 (916.2)
194 (59.15)
3001 (914.9)
T.D.
COAL
SANDSTONE
SILTSTONE
SHALE
LIMESTONE
CALCAREOUS SANDSTONE
PEBBLY SILT
PERCENTAGE OF CORE RECOVERED IN RUN
PERCENTAGE OF CORE LOST IN RUN
STRATIGRAPHIC LOG
NCRP CORE HOLE 28C

Figure A-8. Typical lithology of Logging Creek Priority Study Area.

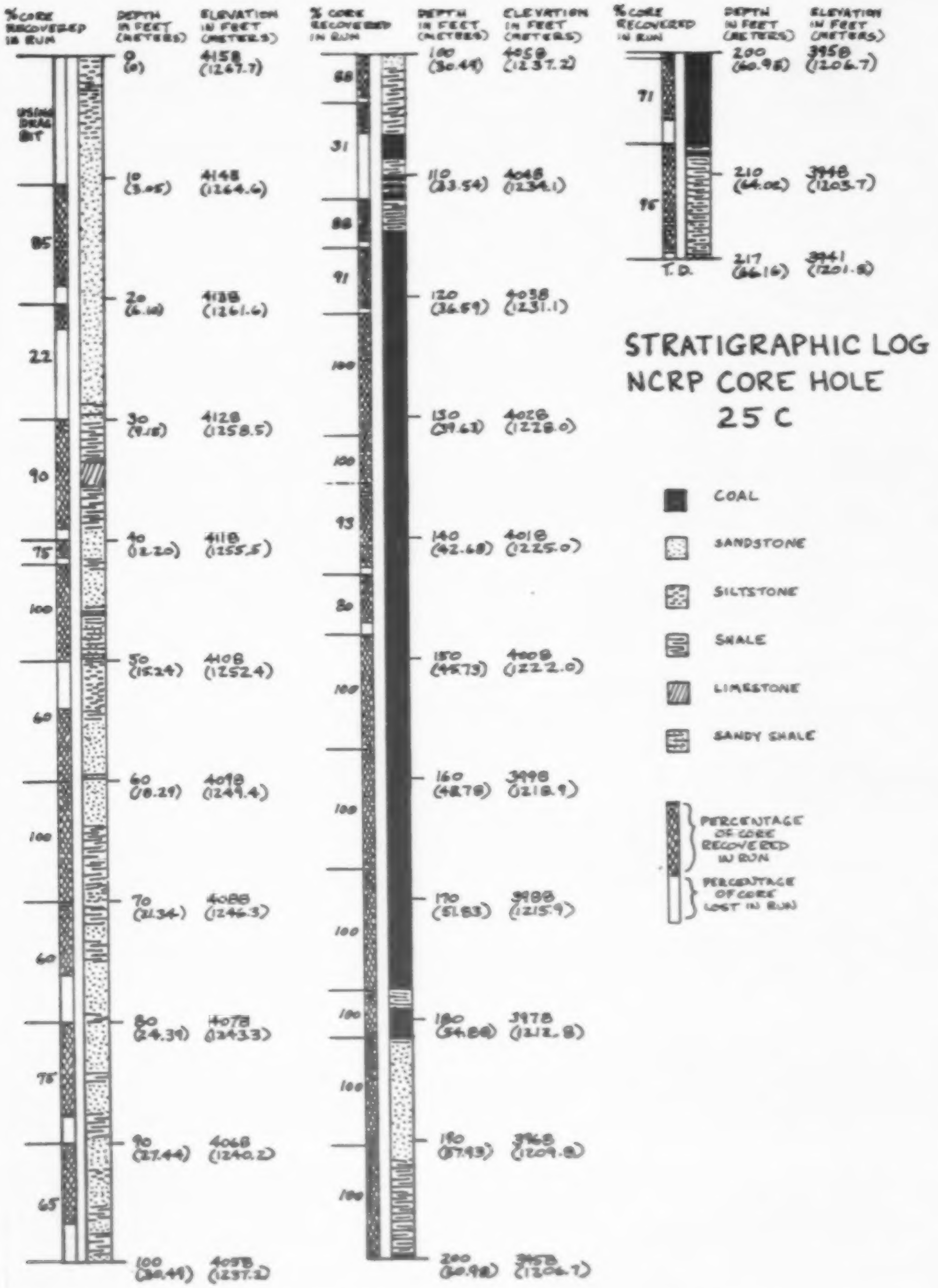

% CORE RECOVERED IN RUN
DEPTH IN FEET (METERS)
ELEVATION IN FEET (METERS)
USING DRAG BIT
0 (0) 4158 (1267.7)
10 (3.05) 4148 (1264.6)
20 (6.10) 4138 (1261.6)
30 (9.15) 4128 (1258.5)
40 (12.20) 4118 (1255.5)
50 (15.24) 4108 (1252.4)
60 (18.29) 4098 (1249.4)
70 (21.34) 4088 (1246.3)
80 (24.39) 4078 (1243.3)
90 (27.44) 4068 (1240.2)
100 (30.49) 4058 (1237.2)
85
22
90
75
100
60
100
60
75
65
100 (30.49) 4058 (1237.2)
110 (33.54) 4048 (1234.1)
120 (36.59) 4038 (1231.1)
130 (39.63) 4028 (1228.0)
140 (42.68) 4018 (1225.0)
150 (45.73) 4008 (1222.0)
160 (48.78) 3998 (1218.9)
170 (51.83) 3988 (1215.9)
180 (54.88) 3978 (1212.8)
190 (57.93) 3968 (1209.8)
200 (60.98) 3958 (1206.7)
68
31
88
91
100
100
93
80
100
100
100
100
100
100
200 (60.98) 3958 (1206.7)
210 (64.02) 3948 (1203.7)
217 (66.16) 3941 (1201.8)
71
95
T.D.
STRATIGRAPHIC LOG
NCRP CORE HOLE
25 C
COAL
SANDSTONE
SILTSTONE
SHALE
LIMESTONE
SANDY SHALE
PERCENTAGE OF CORE RECOVERED IN RUN
PERCENTAGE OF CORE LOST IN RUN

Figure A-9. Typical lithology of Buffalo Jump Priority Study Area.

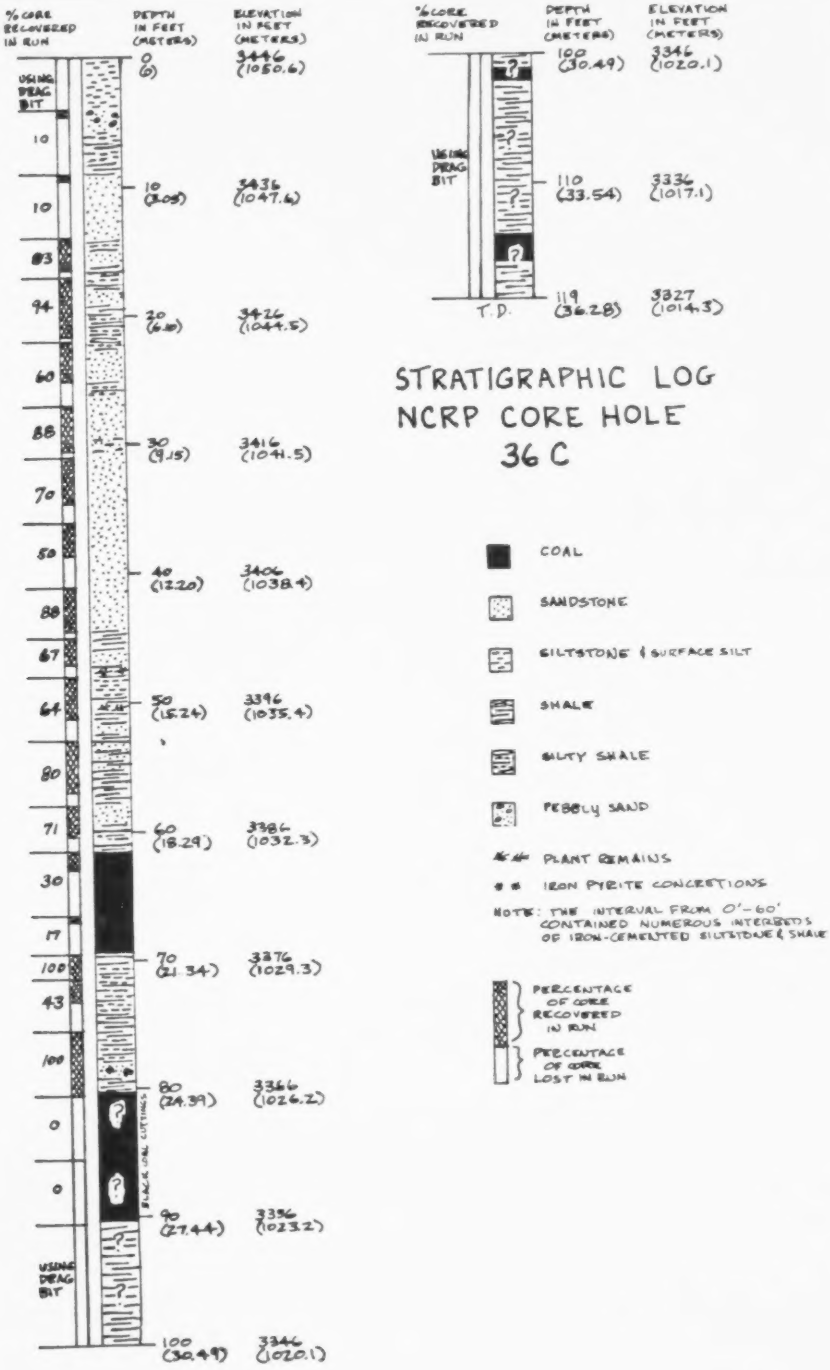

% CORE RECOVERED IN RUN
DEPTH IN FEET (METERS)
ELEVATION IN FEET (METERS)
USING DRAG BIT
10
10
83
94
60
88
70
50
88
67
64
80
71
30
17
100
43
100
0
0
USING DRAG BIT
0 (0)
3446 (1050.6)
10 (3.05)
3436 (1047.6)
20 (6.10)
3426 (1044.5)
30 (9.15)
3416 (1041.5)
40 (12.20)
3406 (1038.4)
50 (15.24)
3396 (1035.4)
60 (18.29)
3386 (1032.3)
70 (21.34)
3376 (1029.3)
80 (24.39)
3366 (1026.2)
BLACK COAL CUTTINGS
90 (27.44)
3356 (1023.2)
100 (30.49)
3346 (1020.1)
% CORE RECOVERED IN RUN
DEPTH IN FEET (METERS)
ELEVATION IN FEET (METERS)
100 (30.49)
3346 (1020.1)
USING DRAG BIT
110 (33.54)
3336 (1017.1)
T.D.
119 (36.28)
3327 (1014.3)
STRATIGRAPHIC LOG
NCRP CORE HOLE
36 C
COAL
SANDSTONE
SILTSTONE & SURFACE SILT
SHALE
SILTY SHALE
PEBBLY SAND
PLANT REMAINS
IRON PYRITE CONCRETIONS
NOTE: THE INTERVAL FROM 0'-60' CONTAINED NUMEROUS INTERBEDS OF IRON-CEMENTED SILTSTONE & SHALE
PERCENTAGE OF CORE RECOVERED IN RUN
PERCENTAGE OF CORE LOST IN RUN

Figure A-10. Typical lithology of Indian Coulee Priority Study Area.

CHAPTER B-1

Transmissivity and hydraulic conductivity values for 127 of the test reported in available driller's logs and the 13 NCRP development tests were calculated using the modified non-equilibrium Theis formula developed by Jacob (1973).

$$Q/s = T/\ (264 \log)(Tt/2{,}693\ r_w^2\ S - 65.5)$$

where:

Q is discharge, in gpm;

s is drawdown, in feet;

T is transmissivity, in gpd/ft;

S is storativity;

r_w is normal radius of well, in feet;

t is time after pumping started, in minutes.

This equation is for a theoretical specific capacity of a well discharging at a constant rate in an isotopic, homogeneous, non-leaky aquifer of infinite extent. It also assumes that well loss is negligible, that the effective radius of the well has not been affected by drilling, and that the production well penetrates and is uncased through the total saturated thickness of the aquifer. Available pump tests provide all information except the transmissivity values. Techniques of graphing type curves of specific capacity versus transmissivity described by Bredehoeft (1976) and Walton (1970) were utilized.

More detailed pump data from 41 wells were analyzed using the Theim (1906) equilibrium equation. Assumption for the Theim equation are similar to the Jacob equation except that the cone of depression is assumed to have reached equilibrium. The basic equation is written for water-table conditions as:

$$Q = P\ (H^2 - h^2)\ /\ 1{,}055\ \log R/r$$

where:

Q is well yield, in gpm;

P is hydraulic conductivity, in gpd/ft^2;

H is saturated thickness of the aquifer before pumping, in ft.;

h is depth of water in the well while pumping, in ft.;

R is radius of the cone of depression;

r is radius of the well, in ft.;

and for a confined system as:

$$Q = Pm (H - h) /528 \log R/r$$

where:

M is thickness of the aquifer, in ft.;

H is static head at bottom of aquifer, in ft.;

The radius of the cone of depression was unknown in addition to the hydraulic conductivity for each test. It has been reported that the cone of depression of a well in unconsolidated material is generally 122m (400 ft) in diameter and 915m (2000 ft) in confined aquifer (Johnson Division, 1972).

The 29 plug tests were performed on sample plugs cut from 5cm (2 in) core samples. Plugs 2.54cm (1 in) in diameter were drilled normal to the vertical axis of the core and used to measure the horizontal and vertical permeability. After drying, air permeability measurements were made using the following formula:

$$K = 2u\ Q\ L\ 1000/A\ (P_1^2 - P_2^2)$$

where:

K is air permeability, in millidarcys;

u is viscosity of air at room temperature;

Q is flow rate, in milliliters/second;

L is length of the plug, in cm;

A is cross sectional area of plug, cm^2;

P_1 is upstream pressure, in atmospheres.

Results of plug tests were assumed to be representativity of the water permeability for the same plug when saturated with water.

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TABLE B-1. NCRP MONITORING WELL INVENTORY GIVING INFORMATION ON WELL LOCATION, DRILLING RECORDS, AND STATIC WATER LEVEL

WELL NCRP	LOCATION	OWNER	ELEVATION FT.	METHOD	DRILLING COMPLETE	METHOD	DIAM.	WELL FT. DEEP	METHOD	TYPE	AQUIFER INTERVAL FT.	CASING LENGTH BLS FT.	CASING LENGTH ALS FT.	TYPE	PERFORATION INTERVAL FT.	TYPE	GROUT INTERVAL FT.	TYPE	PACKING INTERVAL FT.	TYPE	STATIC WATER LEVEL BTC FT.	DATE
#1A	SENWSE Sec28T4SR39E	TRIBE	4060	TM	11-08-75	AR	.49	200	DL	C(Kb)	175-245	200	0.8	P	175-177	S1	196-200	Ce	Bridged	G	116.57	10/76
#1B	SENWSE Sec28T4SR39E	TRIBE	4060	TM	11-13-75	AR	.56	100	DL	C(L)	85-99	976	0.8	P	90-92	S1	[illegible]	Ce	86-95	G	73.60	10/76
#2A	SWNWSE Sec21T5SR39E	TRIBE	4580	TM	11-13-75	AR	.56	240	DL	S/sh	205-240	239	0.57	P	232-234	S1	[illegible]	Ce	225-236	G	157.96	10/76
#2B	SWNWSE Sec21T5SR39E	TRIBE	4580	TM	11-15-75	AR	.56	158	DL	ShC(D)	150-153	158	1.0	P	151-153	S1	[illegible]	Ce	144-155	G	123.65	10/76
#4	SWSWSE Sec22T4SR41E	TRIBE	4385	TM	05-14-76	AR	.56	392	DL	C(Cy)	332-392	392	1.3	P	385-387	S1	37[illegible]-383	Ce	382-392	G	273.75	10/76
#5	NENWNE Sec3T4SR42E	TRIBE	4195	TM	05-27-76	AR	.56	18	DL	SShCl	83-118	118	2.0	P	111-113	S1	92-102	Ce	102-118	G	82.32	10/76
#8A	SWSWSE Sec13T3SR43E	TRIBE	3180	TM	03-19-76	AR	.56	200	DL	C(Kb)	140-200	198	1.7	P	194-197	S1	180-186	Ce	186-198	G	25.21	10/76
#8B	SWSWSE Sec13T3SR43E	TRIBE	3180	TM	07-16-76	AR	.56	30	DL	SG	12-30	30	0.6	P	26-28	S1	22-25	Ce	25-30	G	14.56	10/76
#9A	SENWNE Sec28T3SR44E	TRIBE	2960	TM	03-25-76	AR	.56	101	DL	C(L)	97-101	101	1.8	P	97-100	S1	86-92	Ce	92-101	G	16.79	10/76
#9B	SENWNE Sec28T3SR44E	TRIBE	2960	TM	03-25-76	AR	.56	54	DL	C(L)	48-53	54	1.5	P	50-53	S1	39-45	Ce	45-54	G	22.76	10/76
10A	SENWNW Sec22T2SR44E	TRIBE	2880	TM	04-08-76	C	.50	94	DL	Ss		94	1.95	P	91-93	S1		N		N	9.86	10/76
10B	SENWNW Sec22T2SR44E	TRIBE	2880	TM	04-08-76	AR	.56	20	DL	G	5-20	20	1.45	P	17-19	S1		N		N	10.42	10/76
11A	SENENW Sec36T2SR42E	TRIBE	3302	TM	12-02-75	AR	.56	265	DL	C(Kb)	250-265	265	1.7	P	259-261	S1	[illegible]	Ce	253-262	G	138.08	10/76
11B	SENENW Sec36T2SR42E	TRIBE	3302	TM	12-10-75	AR	.56	49	DL	C(L)	39-45	49	1.5	P	42-44	S1	[illegible]	Ce	35-46	G	45.85	10/76
12A	SENWNW Sec25T5SR42E	TRIBE	3152	TM	12-04-75	AR	.56	120	DL	SG	80-120	110	2.5	P	103-105	S1	98-110	Ce	98-110	G	20.84	10/76
12B	SENWNW Sec25T5SR42E	TRIBE	3152	TM	12-06-75	AR	.56	29	DL	SG	20-29	29	2.3	P	21-23	S1	10-16	Ce	16-27	G	21.85	10/76
13A	NENESW Sec36T6SR38E	TRIBE	3780	TM	04-15-76	C	.50	77	St	Ss		77	0.85	Se		N		N		N	7.56	9/76
13B	NENESW Sec36T6sR38E	Bixby	3780	TM	05-28-64	C	.50	41	DL	Sg	35-40	413	0.80	Se		N		N		N	12.72	9/76
14c	SESWNW Sec22T4SR41E	TRIBE	4200	TM	09-27-76	WR	.25	207	DL	C(Cy)	154-197	207	1.0	P	185-187	S1	159-175	Ce	175-207	G	136.25	10/76
15A	NWSESW Sec8T2SR40E	TRIBE	3775	TM	04-16-76	C	.50	96	St	Ss		96	2.8	P	93-95	S1					10.66	10/76
15B	NWSESW Sec8T2SR40E	TRIBE	3775	TM	04-18-76	C	.50	17	St	SG	8-17	167	1.2	P	12-14	S1		N		N	9.49	10/76
16A	SESWNE Sec13T4SR43E	TRIBE	2999	TM			.50	187	St				135	Se							flows	10/76
16B	SESWNE Sec13T4SR43E	TRIBE	2999	TM	12-12-75	AR	.56	30	DL	SG	20-30	28	1.8	P	22-25	S1	12-18	Ce	18-30	G	15.36	10/76
17A	SWSWNE Sec13T2SR38E	TRIBE	3975	TM	10-20-75	AR	.67	280	DL	Ss	156-164	158	1.7	P	156-158	S1	[illegible]	Ce	153-161	G	118.21	10/76
17B	SWSWNE Sec13T2SR38E	TRIBE	3975	TM	10-20-75	AR	.67	280	DL	Ss	76-94	85	1.0	P	83-85	SL	[illegible]	Ce	80-87	G	82.85	10/76
18	SENWSE Sec25T2SR39E	TRIBE	3451	TM	04-01-76	AR	.56	129	DL	C(L)	121-127	129	1.5	P	125-128	S1	108-120	Ce	120-128	G	88.43	10/76
19	NENESE Sec14T2SR41E	TRIBE	4090	TM	07-09-76	AR	.56	220	DL	Cl	0-78	68	2.0	Se	cavein	N		N		N	DRY	10/76
20A	NENENW Sec18T3SR39E	TRIBE	3342	TM	11-26-75	AR	.56	108	DL	C(L)	100-103	108	1.7	P	101-103	S1	[illegible]	Ce	96-105	G	58.76	10/76
20B	NENENW Sec18T3SR39E	TRIBE	3342	TM	12-01-75	AR	.56	81	DL	C(L)	74-81	81	1.9	P	75-77	S1	[illegible]	Ce	70-78	G	55.50	10/76
21	NWSESW Sec14T2SR43E	TRIBE	3210	TM	04-07-76	AR	.56	118	DL	C(Kb)	91-117	118	2.1	P	114-117	S1	103-109	Ce	109-118	G	95.73	9/76
22	SENWSE Sec28T4SR41E	TRIBE	4279	TM	05-11-76	AR	.56	272	DL	C(Cy)	226-267	272	1.4	P	226-267	S1	210-220	Ce	220-272	G	186.43	10/76
23A	NWSESE Sec16T4SR41E	TRIBE	4060	TM	05-21-76	AR	.56	210	DL	Ss	201-205	210	1.9	P	203-205	S1	190-220	Ce	200-210	G	30.11	10/76
23B	NWSESE Sec16T4SR41E	TRIBE	4060	TM	05-21-76	AR	.56	62	DL	C(L)	52-60	62	1.1	P	58-60	S1	42-52	Ce	52-62	G	29.72	10/76
24	SWSESW Sec24T4SR41E	TRIBE	4171	TM	05-27-76	AR	.56	220	DL	Ss	197-208	220	1.3	P	208-210	S1	180-200	Ce	200-220	G	150.42	10/76
25c	SWSENE Sec11T4SR41E	TRIBE	4158	TM	09-15-76	WR	.25	217	DL	Ss	182-191	217	0.8	P	185-187	S1	155-176	Ce	176-217	G	121.65	10/76
26	SENWSE Sec14T4SR41E	TRIBE	4270	TM	05-25-76	AR	.56	220	DL	C(Cy)	190-219	220	1.2	P	217-219	S1	200-210	Ce	210-220		184.47	10/76
27	SWNWSW Sec35T2SR43E	TRIBE	3380	TM	07-13-76	AR	.56	283	DL	C(Kb)	197-276	283	2.0	P	271-273	S1	259-265	Ce	265-283	G	254.04	10/76
28c	NESESE Sec14T3SR43E	TRIBE	3200	TM	11-05-76	WR	.25	194	DL	C(Kb)	168-186	192	1.0	P	178-180	SL	156-172	Ce	172-192	G	128.40	10/76
29A	NENENE Sec15T3SR43E	TRIBE	3275	TM	07-14-76	AR	.56	260	DL	C(Kb)	178-252	260	2.0	P	247-249	S1	234-242	Ce	242-260	G	43.33	10/76
29B	NENENE Sec15T3SR43E	TRIBE	3275	TM	07-15-76	AR	.56	60	DL	G	30-51	52	2.3	P	45-50	S1	44-47	Ce	47-52	G	47.53	10/76

USE	WELL	LOCATION	OWNER	ELEVATION FT.	METHOD	DRILLING COMPLETE	METHOD	DIAM.	WELL FT. DEEP	METHOD	TYPE	AQUIFER INTERVAL FT.	CASING LENGTH FT.	FT.	TYPE	PERFORATION INTERVAL FT.	TYPE	GROUT INTERVAL FT.	TYPE	PACKING INTERVAL FT.	TYPE	STATIC WATER LEVEL BTC FT.	MSL FT.	DATE	YIELD GPM
M	NCRP 30A	SWSWNW Sec23T3SR44E	TRIBE	3080	TM	07-21-76	AR	.56	124	DL	C(Kb)	91-118	124	1.8	P	114-116	S1	104-111	Ce	111-124	G	85.15		10/76	
M	NCRP 31c	NESESE Sec35T3SR43E	TRIBE	3220	TM	10-05-76	WR	.25	176	DL	C(Kb)	114-159	176	1.0	P	151-153	S1	127-143	Ce	143-176	G	126.38		10/76	
M	NCRP 32	SENENE Sec1 T4SR43E	TRIBE	3180	TM	07-25-76	AR	.52	146	DL	C-KSS	132-140	146	2.2	P	136-140	S1	127-133	Ce	133-146	G	126.64		10/76	
M	NCRP 35A	NESESE Sec3 T2SR40E	TRIBE	3335	TM	06-30-76	AR	.56	297	DL	C(Kb)	278-293	297	2.3	P	285-287	S1	261-279	Ce	279-297	G	43.36		10/76	
M	NCRP 35B	NESESE Sec3 T2SR40E	TRIBE	3335	TM	07-01-76	AR	.56	70	DL	Ss	61-70	70	2.5	P	68-70	S1	38-52	Ce	52-70	G	43.56		10/76	
M	NCRP 36A	SWSW Sec30T2SR40E	TRIBE	3440	TM	07-07-76	AR	.56	122	DL	C-SS	109-120	122	2.1	P	109-120	S1	97-104	Ce	104-122	G	119.82		10/76	
M	NCRP 36C	SWSWSW Sec30T2SR40E	TRIBE	3446	TM	08-15-76	WR	.27	119	DL	C-LSH	109-119	119	2.2	P	109-117	S1	94-102	Ce	102-119	G	101.91		10/76	
M	NCRP 37C	SENWSES S35 T25R39E	TRIBE	3430	TM	08-26-76	WR	.25	106	DL	C(L)	835-87	101	1.4	P	84-86	S1	68-80	Ce	80-101	G	46.87		10/76	
M	NCRP 39A	NWSWNW Sec12T3SR39E	TRIBE	3360	TM	07-02-76	AR	.52	110	DL	Ss	99-110	110	2.6	P	106-108	S1	91-98	Ce	99-110	G	46.97		10/76	
M	NCRP 39B	NWSWNW Sec12T3SR39E	TRIBE	3360	TM	07-02-76	AR	.56	64	DL	SG	53-64	64	2.1	P	59-61	S1	0.-1.5	Ce	None used		19.46		10/76	
M	NCRP 40A	SENENW Sec4 T3SR39E	TRIBE	3560	TM	07-06-76	AR	.56	160	DL	C(L)	153-160	160	2.0	P	156-158	S1	143-150	Ce	150-160	G	50.58		10/76	
M	NCRP 40B	SENENW Sec4 T3SR39E	TRIBE	3560	TM	07-06-76	AR	.55	31	DL	C(R)	26-30	31	2.5	P	28-30	S1	19-25	Ce	25-31	G	30.01		10/76	
D	RBCW #2	NWSW Sec1 T5SR38E	SMALL	3691	TM	03-09-73		.5	80	DL	Ss	62-80	63	1.3	Se							28.18		10/76	15
D	RBCW #3	SWSWNW Sec26T4SR38E	LAFEVER	3600	TM	06-05-64			66	DL	S-G	44-66	66	1.66	P							17.79		10/76	25
D	RBCW #4	SWSWSW Sec36T3SR38E	RUSSELL	3500	TM	03-09-72		.5	103	DL	Ss	35-103	103	1.0	Se	60-102	P					56.44		9/76	
D	RBCW #7	NWNESW Sec28T3SR39E	GLENMORE	3394	TM	08-07-73	C	.5	59	DL	SG	47-53	57	1.55	S	41-53	P	0-16	Ce		N	26.29		10/76	10
D	RBCW #8	NENENW Sec18T3SR40E	KILLSNIGHT	3320	TM	09-08-73	C	.5	102	DL	Ss	78-95	47 42-100	1.66	Se P	82-102	S1	6-16	Ce		N	50.52		10/76	10
D	RBCW #9	NENWNE Sec24T2SR40E	REDNECK	3240	TM	07-14-73	C	.5	75	DL	SS	69-73	72	1.5	P	68-72	P	6-16	Ce		N	30.45		10/76	10
D	RBCW #10	SESWSW Sec18T2SR41E	MED ELK	3189	TM	05-21-67		.5	63	DL	G	18-63	62			55-63	P					16.77		7/76	
D	LDCW #1	NENWNW Sec34T3SR42E	SPANG	3980	TM	11-12-71	AR	.5	77	DL	Ss	62-77	77	.95		69-77			N		N	23.48		10/76	12
D	LDCW #2	SWSENE Sec13T3SR41E	CHARETTE	3640	TM	11-20-73	C	.5	117	DL	Ss	60-117	0-64 54-117	1.90	Se	97-117	S1	6-16	Ce		N	65.77		11/76	14
D	LDCW #3	SWNENE Sec 3T3SR41E	STEVENS	3402	TM	12-03-73	C	.5	220	DL	C()Sh	174-220	0-84 80-220	1.45	[illegible]	190-220		6-16	Ce		N	56.44		10/76	3
D	LDCW #4	NWSWNE Sec 1T3SR41E	SIMPSON	3556	TM	09-05-73	C	.5	72	DL	C()Sh	38-72	0-47 46-72	2.20	P	43-46		6-16			N	14.19		10/76	10
D	LDCW #5	NENWNW Sec28T2SR41E	KELLUM	3300	TM	07-11-73	C	.5	175	DL	Ss	172-175	0-84 80-175	1.30		135-175	S1	6-16	Ce		N	79.03		10/76	10
D	LDCW #6	SESESE Sec17T2SR41E	KINZEL	3215	TM	02-22-73		.5	60	DL	C/G	24-60	42	0.37	Se							26.71		10/76	
D	LDCW #7	NENESE Sec30T2SR42E	POND	3740	TM	10-29-74	FR	.5	120	DL	Ss	80-120	120	1.30	P	85-120	S1		N		R	76.84		10/76	5
D	LDCW #8	NWSENE Sec34T2SR41E	MC MAKIN	3380	TM	05-31-75	C	.5	98	DL	Sh	91-98	98	1	Se	91-98	S1	0-10	B		N	64.83		6/76	25
M	USGS #1	SESENE Sec 9T3SR44E	TRIBE	2955	TM	73		.15	102	DL	S-G	60-102	100	295	Se							42.07		10/76	
M	USGS #3	SWSENE Sec19T2SR41E	TRIBE	3170	TM	73		.15	42	ST			42	2.40	Se							8.89		10/76	
M	USGS #4	NWSWNE Sec31T2SR41E	TRIBE	3310	TM	73		.5	77	ST			77	0.25	Se							72.50		10/76	
D	MCW #1	NWSENE Sec 5T4SR40E	BOWLAND	3690	TM	11-10-71	AR	.5	95	DL	C1	45-55	55	.27	S	45-55	S1		N		N	45.40		10/76	12
D	MCW #2	NENWSW Sec 6T4SR41E	R HARRIS	3640	TM	11-17-73	C	.5	200	DL	Ss	130-180 180-200		1.3		180-200	S1	0-16	Ce		N	66.36		10/76	4
D	MCW #3	SWNESE Sec26T3SR40E	L HARRIS	3460	TM	07-24-73	C	.5	57	DL	SG	54-57	57	1.2		52-56	S1	6-16	Ce		N	14.46		10/76	10
D	MCW #4	SESESW Sec13T2SR40E	SPANG	3374	TM	07-20-73	C	.5	91	DL	SS	80-91		1.5		80-91	S1	6-16	Ce		N	46.95		10/76	10
D	MCW #5	SENWNW Sec35T5SR43E	YELLOWROBE	3280	TM	08-30-73	C	.38	42	DL	SG	20-42	42	1.5		36-41	S1	6-16	Ce		N	16.67		10/76	10
D	TRW #1	NENESW Sec 7T5SR42E	TRIBAL	3130	TM			.5	71					2.5	P							48.85		10/76	
D	TRW #2	SWNE Sec24T3SR44E	FISHER	3090	TM			.5	220					2.70	P							11.28		9/76	
D	TRW #3	SWNW Sec28T3SR44E	BEAR	2985	TM	9-11-73	C	.5	80	DL	Ss	75-80		2.0		70-80	S1	6-16	Ce		N	48.28		9/76	9
D	TRW #4	SWNE Sec16T3SR44E	LITTLECOYOTE	2930	TM	02-16-73		.5	63	DL	G		63	1.73	Se							29.91		10/76	
D	TRW #5	SESW Sec34T2SR44E	BRADY	2915	TM	04-02-73	AR	.5	160	DL	Ss	98-160	105	1.7	Se		N		N		N	43.87		10/76	8
D	TRW #6	SESW Sec22T2SR44E	TWOTWO	2890	TM	02-24-68		.5	68	DL	S	66-68	68	1.8	Se							29.74		11/76	15
D	TRW #7	SESWNE Sec16T2SR44E	MED ELK	2880	TM	70's		.5	53	DL	SG	45-53	53	0.9	Se	48-52	S1					20.46		10/76	
D	TRW #8	SESWSE Sec26T5SR42E	[illegible]	3100	TM				17.9				17.9	2.1	Se							9.95		10/76	
D	TRW #9	SESESE Sec36T2SR43E	TRIBAL	3302	TM			.5	259	St	C(Kb)			4.0	Se							208.47		11/76	
D	TRW #10	SENWNE Sec33T3SR43E	[illegible]	3580	TM		AR	.5	172	DL	Ss											37.59		11/76	

TABLE B-2. ANALYTICAL METHODS USED BY ENERGY AND ENVIRONMENTAL RESOURCE CONSULTANTS, INC. IN THE PERFORMANCE OF ANALYTICAL WORK UNDER GRANT NO. R803566-01

(a)

CONSTITUENT	METHOD	DETECTION LIMIT mg./l.
Potassium	EPA* page 143	0.002
Sodium	EPA page 141	0.005
Calcium	Std. Methods** page 189 306C	1
	EPA page 103	0.01
Magnesium	Std. Methods page 223 313 C	1
	EPA page 115	0.001
Sulfate	Std. Methods gravimetric	15
	page 495 427 B turbidimetric	2
Chloride	Std. Methods Argentometric	1
	page 303 408 A Mercurimetric	0.1
Carbonate	Std. Methods page 102	1
Bicarbonate	Std. Methods page 102	1
Total Dissolved Solids	EPA page 266	10
Fluoride	EPA page 65	0.05
Silica (SiO_2)	Std. Methods page 487	1
Nitrate	EPA page 201	0.1 as NO_3 0.02 NO_3(N)
Total Phosphorus as P	EPA page 249	0.01

*EPA refers to Manual of Methods for Chemical Examinations of Water and Wastes, 625-6-74-003

**Std. Methods refers to Standard Methods for the Examination of Water and Waste Water, 14th Edition.

(b) -

CONSTITUENT	METHODS	DETECTION LIMIT mg./l.
Total Hardness as $CaCO_3$	Std. Methods** page 103	1
Alkalinity as $CaCO_3$	Std. Methods page 102	2
Non-carbonate Hardness as $CaCO_3$	Std. Methods page 201	1
Copper	EPA* page 108	0.02
Mercury	EPA page 118	0.0002
Lead	EPA page 112	0.01
Arsenic	EPA page 95	0.002
Selenium	EPA page 145	0.002
Aluminum	EPA page 92	0.05
Vanadium	EPA page 153	0.002
Strontium	Std. Methods page 257	0.01
Manganese	EPA page 116	0.01
Iron	EPA page 110	0.01
Lithium	Std. Methods page 219	0.01

*EPA refers to Manual of Methods for Chemical Examinations of Water and Wastes, 625-6-74-003

**Std. Methods refers to Standard Methods for the Examination of Water and Waste Water, 14th Edition

TABLE B-3. WATER QUALITY DATA

WELL NCRP 16B (UNCONSOLIDATED)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	13.71	4.80	7.00
SODIUM	PPM	243	21.85	7.00
CALCIUM	PPM	62.86	24.84	7.00
MAGNESIUM	PPM	39.00	14.48	7.00
SULFATE	PPM	362	160	7.00
CHLORIDE	PPM	9.57	2.92	7.00
CARBONATE	PPM	88.29	185	7.00
BICARBONATE	PPM	562	156	7.00
FLOURIDE	PPM	0.96	0.10	7.00
SILICON DIO	PPM	21.00	4.96	7.00
TOTAL P	PPM	0.09	0.09	7.00
NITRATE	PPM	0.27	0.89	7.00
POTASSIUM	EPM	0.35		
SODIUM	EPM	10.56		
CALCIUM	EPM	3.14		
MAGNESIUM	EPM	3.21		
SULFATE	EPM	7.54		
CHLORIDE	EPM	0.27		
CARBONATE	EPM	2.94		
BICARBONATE	EPM	9.22		
FLOURIDE	EPM	0.05		
NITRATE	EPM	0.00		
TOTAL CATIONS		17.26	1.75	7.00
TOTAL ANIONS		19.95	5.68	7.00
DEVIATION		117	39.56	7.00
TDS (calc.)		1039	112	7.00
TDS @180		916	384	7.00
TOTAL HARDNESS		317	47.91	7.00
ALKALINITY		433	20.33	7.00
NON-CARB HARD		0.00	0.00	7.00
LAB CONDUCTIVITY		1579	156	7.00
FIELD COND.		0.00	0.00	0.00
LAB pH		7.99	0.20	7.00
FIELD pH		7.20	0.35	6.00

WELL NCRP 36B (ROSEBUD COAL AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	14.00	3.02	7.00
SODIUM	PPM	588	43.93	7.00
CALCIUM	PPM	248	41.57	7.00
MAGNESIUM	PPM	160	11.84	7.00
SULFATE	PPM	2073	39.55	7.00
CHLORIDE	PPM	12.14	3.68	7.00
CARBONATE	PPM	0.00	0.00	7.00
BICARBONATE	PPM	528	82.57	7.00
FLOURIDE	PPM	0.23	0.05	7.00
SILICON DIO	PPM	22.86	14.96	7.00
TOTAL P	PPM	0.05	0.05	7.00
NITRATE	PPM	2.51	2.41	7.00
POTASSIUM	EPM	0.36		
SODIUM	EPM	25.57		
CALCIUM	EPM	12.38		
MAGNESIUM	EPM	13.13		
SULFATE	EPM	43.17		
CHLORIDE	EPM	0.34		
CARBONATE	EPM	0.00		
BICARBONATE	EPM	8.66		
FLOURIDE	EPM	0.01		
NITRATE	EPM	0.00		
TOTAL CATIONS		51.43	0.63	7.00
TOTAL ANIONS		52.09	1.01	7.00
DEVIATION		101	1.47	7.00
TDS (calc.)		3355	33.70	7.00
TDS @180		3501	83.55	7.00
TOTAL HARDNESS		1275	109	7.00
ALKALINITY		433	67.76	7.00
NON-CARB HARD		842	111	7.00
LAB CONDUCTIVITY		4182	406	7.00
FIELD COND.		2790	0.00	1.00
LAB pH		7.81	0.20	7.00
FIELD pH		7.08	0.53	6.00

WELL NCRP 29A

(Knobloch coal aquifer)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	6.20	4.45	5.00
SODIUM	PPM	462	49.96	5.00
CALCIUM	PPM	6.40	7.09	5.00
MAGNESIUM	PPM	30.40	54.81	5.00
SULFATE	PPM	492	404	5.00
CHLORIDE	PPM	9.60	2.24	5.00
CARBONATE	PPM	43.20	12.24	5.00
BICARBONATE	PPM	676	42.61	5.00
FLOURIDE	PPM	5.34	2.08	5.00
SILICON DIO	PPM	7.60	2.24	5.00
TOTAL P	PPM	0.07	0.07	5.00
NITRATE	PPM	0.28	0.62	5.00
POTASSIUM	EPM	0.16		
SODIUM	EPM	20.10		
CALCIUM	EPM	0.32		
MAGNESIUM	EPM	2.50		
SULFATE	EPM	10.24		
CHLORIDE	EPM	0.27		
CARBONATE	EPM	1.44		
BICARBONATE	EPM	11.08		
FLOURIDE	EPM	0.28		
NITRATE	EPM	0.00		
TOTAL CATIONS		23.08	7.11	5.00
TOTAL ANIONS		23.24	7.69	5.00
DEVIATION		100	2.46	5.00
TDS (calc.)		1382	502	5.00
TDS @180		1404	495	5.00
TOTAL HARDNESS		141	243	5.00
ALKALINITY		626	33.82	5.00
NON-CARB HARD		13.40	26.80	5.00
LAB CONDUCTIVITY		2076	466	5.00
FIELD COND.		1310	0.00	1.00
LAB pH		8.62	0.10	5.00
FIELD pH		7.23	0.91	3.00

WELL NCRP 22 (CANYON COAL AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	10.50	3.10	6.00
SODIUM	PPM	725	31.51	6.00
CALCIUM	PPM	14.67	3.59	6.00
MAGNESIUM	PPM	6.50	4.86	6.00
SULFATE	PPM	639	42.62	6.00
CHLORIDE	PPM	13.00	2.58	6.00
CARBONATE	PPM	83.00	73.03	6.00
BICARBONATE	PPM	1007	139	6.00
FLOURIDE	PPM	0.93	0.21	6.00
SILICON DIO	PPM	11.83	1.07	6.00
TOTAL P	PPM	0.13	0.39	6.00
NITRATE	PPM	0.07	0.84	6.00
POTASSIUM	EPM	0.27		
SODIUM	EPM	31.54		
CALCIUM	EPM	0.73		
MAGNESIUM	EPM	0.53		
SULFATE	EPM	13.30		
CHLORIDE	EPM	0.37		
CARBONATE	EPM	2.77		
BICARBONATE	EPM	16.51		
FLOURIDE	EPM	0.05		
NITRATE	EPM	0.00		
TOTAL CATIONS		57.07	58.79	7.00
TOTAL ANIONS		51.05	44.48	7.00
DEVIATION		96.69	7.25	7.00
TDS (calc.)		1988	93.81	6.00
TDS @180		1963	81.04	6.00
TOTAL HARDNESS		62.17	23.40	6.00
ALKALINITY		964	37.01	6.00
NON-CARB HARD		0.00	0.00	6.00
LAB CONDUCTIVITY		2892	208	6.00
FIELD COND.		2077	245	3.00
LAB pH		8.52	0.33	6.00
FIELD pH		7.75	0.29	6.00

WELL NCRP 4 (CANYON COAL AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	13.87	2.80	8.00
SODIUM	PPM	215	37.14	8.00
CALCIUM	PPM	282	327	8.00
MAGNESIUM	PPM	64.37	37.73	8.00
SULFATE	PPM	550	36.03	8.00
CHLORIDE	PPM	9.50	1.94	8.00
CARBONATE	PPM	0.00	0.00	8.00
BICARBONATE	PPM	697	114	8.00
FLOURIDE	PPM	0.31	0.07	8.00
SILICON DIO	PPM	15.50	1.80	8.00
TOTAL P	PPM	0.15	0.16	8.00
NITRATE	PPM	0.04	0.87	8.00
POTASSIUM	EPM	0.35		
SODIUM	EPM	9.35		
CALCIUM	EPM	14.07		
MAGNESIUM	EPM	5.30		
SULFATE	EPM	11.46		
CHLORIDE	EPM	0.27		
CARBONATE	EPM	0.00		
BICARBONATE	EPM	11.42		
FLOURIDE	EPM	0.02		
NITRATE	EPM	0.00		
TOTAL CATIONS		29.07	17.48	8.00
TOTAL ANIONS		23.10	2.12	8.00
DEVIATION		92.78	22.33	8.00
TDS (calc.)		1353	119	8.00
TDS @180		1400	80.96	8.00
TOTAL HARDNESS		655	85.32	8.00
ALKALINITY		571	93.77	8.00
NON-CARB HARD		85.50	52.54	8.00
LAB CONDUCTIVITY		1985	61.40	8.00
FIELD COND.		1420	0.00	1.00
LAB pH		7.60	0.17	8.00
FIELD pH		6.82	0.31	7.00

WELL TRW 5 (Sandstone aquifer)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	12.00	2.93	7.00
SODIUM	PPM	165	10.99	7.00
CALCIUM	PPM	68.86	5.51	7.00
MAGNESIUM	PPM	45.43	2.61	7.00
SULFATE	PPM	240	5.95	7.00
CHLORIDE	PPM	8.86	1.96	7.00
CARBONATE	PPM	0.00	0.00	7.00
BICARBONATE	PPM	573	14.35	7.00
FLOURIDE	PPM	1.01	0.34	7.00
SILICON DIO	PPM	17.57	2.72	7.00
TOTAL P	PPM	0.05	0.08	7.00
NITRATE	PPM	0.03	0.93	7.00
POTASSIUM	EPM	0.31		
SODIUM	EPM	7.20		
CALCIUM	EPM	3.44		
MAGNESIUM	EPM	3.74		
SULFATE	EPM	5.01		
CHLORIDE	EPM	0.25		
CARBONATE	EPM	0.00		
BICARBONATE	EPM	9.40		
FLOURIDE	EPM	0.05		
NITRATE	EPM	0.00		
TOTAL CATIONS		14.68	0.37	7.00
TOTAL ANIONS		14.64	0.26	7.00
DEVIATION		99.81	1.95	7.00
TDS (calc.)		824	16.32	7.00
TDS @180		830	16.43	7.00
TOTAL HARDNESS		359	12.86	7.00
ALKALINITY		470	11.65	7.00
NON-CARB HARD		0.00	0.00	7.00
LAB CONDUCTIVITY		1275	47.96	7.00
FIELD COND.		900	0.00	1.00
LAB pH		7.70	0.18	7.00
FIELD pH		7.10	0.65	6.00

WELL NCRP 24 (CANYON COAL AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	13.14	3.36	7.00
SODIUM	PPM	105	8.24	7.00
CALCIUM	PPM	52.29	10.89	7.00
MAGNESIUM	PPM	36.00	5.07	7.00
SULFATE	PPM	106	11.52	7.00
CHLORIDE	PPM	5.57	1.68	7.00
CARBONATE	PPM	0.86	2.10	7.00
BICARBONATE	PPM	490	13.50	7.00
FLOURIDE	PPM	0.95	0.07	7.00
SILICON DIO	PPM	24.43	8.97	7.00
TOTAL P	PPM	0.19	0.31	7.00
NITRATE	PPM	1.84	0.73	7.00
POTASSIUM	EPM	0.34		
SODIUM	EPM	4.55		
CALCIUM	EPM	2.61		
MAGNESIUM	EPM	2.96		
SULFATE	EPM	2.21		
CHLORIDE	EPM	0.16		
CARBONATE	EPM	0.03		
BICARBONATE	EPM	8.03		
FLOURIDE	EPM	0.05		
NITRATE	EPM	0.00		
TOTAL CATIONS		10.46	0.47	7.00
TOTAL ANIONS		10.43	0.39	7.00
DEVIATION		99.86	2.61	7.00
TDS (calc.)		559	27.05	7.00
TDS @180		578	38.47	7.00
TOTAL HARDNESS		279	13.13	7.00
ALKALINITY		403	11.61	7.00
NON-CARB HARD		0.00	0.00	7.00
LAB CONDUCTIVITY		915	48.56	7.00
FIELD COND.		605	45.00	2.00
LAB pH		7.91	0.20	7.00
FIELD pH		6.99	0.33	6.00

WELL NCRP 5 (Clinker aquifer)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	5.67	0.94	3.00
SODIUM	PPM	12.33	1.89	3.00
CALCIUM	PPM	66.00	0.00	3.00
MAGNESIUM	PPM	19.67	0.47	3.00
SULFATE	PPM	12.67	7.72	3.00
CHLORIDE	PPM	3.67	0.47	3.00
CARBONATE	PPM	10.00	14.14	3.00
BICARBONATE	PPM	295	23.61	3.00
FLOURIDE	PPM	1.01	0.63	3.00
SILICON DIO	PPM	17.00	6.48	3.00
TOTAL P	PPM	0.07	0.06	3.00
NITRATE	PPM	1.70	0.92	3.00
POTASSIUM	EPM	0.14		
SODIUM	EPM	0.54		
CALCIUM	EPM	3.29		
MAGNESIUM	EPM	1.62		
SULFATE	EPM	0.26		
CHLORIDE	EPM	0.10		
CARBONATE	EPM	0.33		
BICARBONATE	EPM	4.83		
FLOURIDE	EPM	0.05		
NITRATE	EPM	0.00		
TOTAL CATIONS		5.59	0.07	3.00
TOTAL ANIONS		5.56	0.20	3.00
DEVIATION		99.34	2.43	3.00
TDS (calc.)		275	10.99	3.00
TDS @180		296	15.96	3.00
TOTAL HARDNESS		245	2.50	3.00
ALKALINITY		258	6.24	3.00
NON-CARB HARD		0.00	0.00	3.00
LAB CONDUCTIVITY		522	22.48	3.00
FIELD COND.		335	0.00	1.00
LAB pH		7.80	0.36	3.00
FIELD pH		7.08	0.22	3.00

WELL LDCW 1 (SANDSTONE AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	5.64	0.98	11.00
SODIUM	PPM	23.73	3.77	11.00
CALCIUM	PPM	66.09	6.56	11.00
MAGNESIUM	PPM	24.55	4.31	11.00
SULFATE	PPM	16.18	4.59	11.00
CHLORIDE	PPM	5.73	2.05	11.00
CARBONATE	PPM	0.00	0.00	11.00
BICARBONATE	PPM	366	16.38	11.00
FLOURIDE	PPM	0.80	0.11	11.00
SILICON DIO	PPM	20.27	4.90	11.00
TOTAL P	PPM	0.03	0.06	11.00
NITRATE	PPM	0.92	1.31	11.00
POTASSIUM	EPM	0.14		
SODIUM	EPM	1.03		
CALCIUM	EPM	3.30		
MAGNESIUM	EPM	2.02		
SULFATE	EPM	0.34		
CHLORIDE	EPM	0.16		
CARBONATE	EPM	0.00		
BICARBONATE	EPM	5.99		
FLOURIDE	EPM	0.04		
NITRATE	EPM	0.00		
TOTAL CATIONS		6.49	0.16	11.00
TOTAL ANIONS		6.49	0.24	11.00
DEVIATION		99.93	2.46	11.00
TDS (calc.)		323	7.69	11.00
TDS @180		330	19.81	11.00
TOTAL HARDNESS		265	4.15	11.00
ALKALINITY		300	13.57	11.00
NON-CARB HARD		0.00	0.00	11.00
LAB CONDUCTIVITY		545	77.81	11.00
FIELD COND.		410	0.00	1.00
LAB pH		7.66	0.59	11.00
FIELD pH		6.76	0.30	8.00

WELL NCRP 13B (UNCONSOLIDATED AQUIFER)

DATE		MEAN	ST.DEV	#
POTASSIUM	PPM	12.29	1.75	7.00
SODIUM	PPM	60.14	4.29	7.00
CALCIUM	PPM	127	39.30	7.00
MAGNESIUM	PPM	53.57	21.93	7.00
SULFATE	PPM	185	6.41	7.00
CHLORIDE	PPM	9.43	1.05	7.00
CARBONATE	PPM	6.86	16.80	7.00
BICARBONATE	PPM	559	41.16	7.00
FLOURIDE	PPM	0.66	0.07	7.00
SILICON DIO	PPM	24.29	4.13	7.00
TOTAL P	PPM	0.08	0.09	7.00
NITRATE	PPM	0.94	1.35	7.00
POTASSIUM	EPM	0.31		
SODIUM	EPM	2.62		
CALCIUM	EPM	6.33		
MAGNESIUM	EPM	4.41		
SULFATE	EPM	3.85		
CHLORIDE	EPM	0.27		
CARBONATE	EPM	0.23		
BICARBONATE	EPM	9.16		
FLOURIDE	EPM	0.03		
NITRATE	EPM	0.00		
TOTAL CATIONS		13.67	0.36	7.00
TOTAL ANIONS		13.47	0.36	7.00
DEVIATION		98.57	1.73	7.00
TDS (calc.)		729	23.88	7.00
TDS @180		745	29.78	7.00
TOTAL HARDNESS		537	21.76	7.00
ALKALINITY		469	19.35	7.00
NON-CARB HARD		67.29	17.19	7.00
LAB CONDUCTIVITY		1110	144	7.00
FIELD COND.		765	45.00	2.00
LAB pH		7.77	0.15	7.00
FIELD pH		7.18	0.46	5.00

TABLE B-4. SUMMARY OF PUMP TEST DATA FROM WELL LOGS OF DOMESTIC WELLS COMPLETED ON NORTHERN CHEYENNE RESERVATION

Aquifer	# of tests	Length of tests (Days)	Average Saturated Thickness		Storage Coeffi-cient	Average Transmissivity		Average Hydraulic Conductivity	
			m	ft		m^2/day	ft^2/day	m/day	ft/day
Rosebud-McKay coal Range -	4	0.08-0.13	10	30	1×10^{-5}	13 16-10	139 167-107	8.5 20-2	28 67-5
Shale and Rosebud-McKay coal Range -	3	0.08-21	13.7	45	4×10^{-5}	22 60-0.5	241 642-5	1.8 5-0.04	6 16-0.12
Sandstone and Pawnee-Sawyer coal	1	0.04	20.4	67	4×10^{-5}	0.7	8	.04	0.12
Sandstone and Sawyer coal	1	0.17	3.7	12	4×10^{-5}	18	190	1.15	5
Sandstone and Knobloch coal	1	0.04	14.6	48	4×10^{-5}	3	28	0.18	0.6
Sandstone and Rosebud-McKay coal	8	0.04-0.17	12.6	40	4×10^{-5}	4	41	1.2	4
Sandstone and Local coal below Rosebud McKay coal Range -	3	0.04-0.17	8.6	28	4×10^{-5}	35 47-25	379 508-267	8.8 19-1	29 64-5
Sand and Gravel and Wall coal	1	0.04	5.2	17	0.01	10	107	1.8	6
Sand and Gravel and Rosebud-McKay Coal Range -	2	0.04	5.5	18	0.01	11 20-2	119 214-24	1.8 3-0.5	6 11-1.6
Shale Range -	2	0.04-0.13	10	33	5×10^{-5}	24 38-16	291 414-167	2.7 3-2	9 10-7
Sandstone and Shale Range -	6	0.01-0.04	16.2	53	5×10^{-5}	14 40-4	149 428-47	1.2 4-0.2	4 13-1
Clinker	1	0.13	3.6	12	0.1	8	87	2.1	7
Clinker and Sand and Gravel	1	0.04	14.0	46	0.1	12	134	0.91	3
Clinker and Sandstone	1	0.17	25.6	84	0.1	27	294	1.2	4

TABLE B-4(continued)

Aquifer	# of Tests	Length of Tests (Days)	Average Saturated Thickness		Storage Coefficient	Average Transmissivity		Average Hydraulic Conductivity	
			m	ft		m^2/day	ft^2/day	m/day	ft/day
Tongue River Alluvium range -	22	0.04-0.17	10.8	35.5	0.15	85 146-0.6	918 5142-19	6.4 26-0.1	21 84-0.4
Rosebud Creek Alluvium range -	22	0.02-0.17	12.9	42.4	0.12	53 216-3	572 2325-27	5.8 33-0.2	19 110-0.7
Lame Deer Creek Alluvium range -	12	0.04-0.17	10.6	34.6	0.12	128 427-10	1372 4599-107	18.6 117-0.9	61 383-3
Muddy Creek Alluvium range -	7	0.04-0.08	9.0	29.6	0.12	85 165-17	915 1780-180	12.2 28-1	40 94-4
Lower Tongue River Member Sandstone Tongue River Valley range -	17	0.4-0.17	9.4	31.0	3x10-5	48 167-3	531 1805-31	9.2 55-0.1	30 180-0.4
Lower Tongue River Member Sandstone Rosebud Creek Valley range -	31	0.04-0.14	7.9	26.0	$3x10^{-5}$	34 143-1	361 1537-10	7.3 36-0.2	24 117-0.8
Lower Tongue River Member-Knobloch Unit Sandstone, Lame Deer Creek Valley range -	16	0.02-0.14	9.3	30.5	$3x10^{-5}$	36 137-2	389 1471-24	8.2 56-0.4	27 187-1.2
Lower Tongue River Member Sandstone, Muddy Creek Valley range -	5	0.02-0.14	4.9	16.2	$3x10^{-5}$	24 67-4	258 722-39	6.4 15-0.3	21 48-0.9
Wall Coal	1	0.04	10.4	34	$3x10^{-5}$	15	160	1.5	5

TABLE B-5. SUMMARY OF PUMP TEST DATA FROM NCRP MONITORING WELLS, NORTHERN CHEYENNE RESERVATION

Aquifer	# of Test	Length of Tests days	Saturated Thickness		Storage Coefficient	Transmissivity		Hydraulic Conductivity	
			m	ft		m^2/day	ft^2/day	m/day	ft/day
Anderson Coal									
NCRP 4	1	0.03	20.4	67	7x10^{-5}	1	11	0.05	0.2
NCRP 22	1	0.08	12.2	40	4x15^{-5}	0.5	5	0.04	0.1
NCRP 24	1	0.02	9.8	32	3x10^{-5}	1	13	0.02	0.4
Average -	3	0.04	14.1	46	5x10^{-5}	1	10	0.07	0.23
range -		0.8-0.2				1-0.5	14-5	0.1-0.04	0.4-0.12
Knobloch Coal									
NCRP 8A	1	0.4	18.3	60	6x10^{-5}	9	98	0.5	1.6
NCRP 21A	1	0.02	7.9	26	3x10^{-5}	2	24	0.3	0.9
NCRP 30A	1	0.01	10.1	33	3x10^{-5}	11	120	0.9	2.9
NCRP 29A	1	0.01	22.6	74	7x10^{-5}	17	187	0.8	2.5
Average -	4	0.02	14.7	48	6x10^{-5}	3	70	0.6	2.01
range -		0.04-0.01				17-3	187-24	0.9-0.3	3-0.9
Rosebud-McKay Coal									
NCRP 18	1	0.02	2.0	6	0.6x10^{-5}	0.07	0.7	0.03	0.1
CNRP 40A	1	0.01	2.0	7	0.7x10^{-5}	15	160	7	23
Average -	2	0.015	2.0	6.5	0.65x10^{-5}	22	81	3.5	11.5
range -		0.02-0.01				15-0.07	160-0.7	7-0.3	23-0.1
Robinson Coal									
NCRP 35A	1	0.04	4.6	15	1x10^{-5}	1	12	0.4	0.8
Local Coal below Rosebud McKay Coal									
NCRP 20A	1	0.01	0.9	3	0.3x10^{-5}	1	16	2	5
NCRP 9A	1	0.02	1.2	4	0.4x10^{-5}	4	48	4	12
average -	2	0.015	1.0	3.5	0.35x10^{-5}	3	32	2.7	9
range -		0.07-0.01				4-1	48-16	4-2	12-5
Clinker									
NCRP 5	1	0.01	10.4	34	0.1	0.5	5	0.04	0.1

TABLE B-6. SUMMARY OF LITERATURE SEARCH FOR PUMP TEST DATA IN THE FORT UNION FORMATION, SOUTHEASTERN MONTANA

Aquifer	Type of Test	Length of Tests (Days)	Saturated Thickness		Transmissivity		Hydraulic Conductivity		Reference
			m	ft	m^2/day	ft/day	m/day	ft/day	
Dietz Coal									
Dietz#1	pump		15.2	50	42	134	0.8	2.7	Van Voast, 1974
Dietz#2	pump		6.1	20	6	67	1.0	3.3	Van Voast, 1974
Dietz#1, #2,#3 average(14)	pump	0.3-0.01	4.9	16	6	63	1.2	3.9	Van Voast and Hedges,1975
range	pump						0.9-1.5	3-5	USGS and MDSL,1977
Dietz Clinker	assumed from Spring data				232	2500	45.7-61	150-200	Van Voast and Hedges 1975
Dietz Clinker									USGS and MDSL,1977
Canyon Coal(1)	pump		6.7	22	4	40	0.6	2	BLM, 1975
Knobloch Coal (1)	pump		18.3	60	2.5	27	0.14	0.45	BLM, 1975
Sandstone and Shale Interburden									
Weathered sandstone and siltstone	plug		-	-	8.6	93.6	17.1	56.2	BIA, 1976
Unweathered							$1.1x10^{-5}$	$3.75x10^{-5}$	BIA, 1976
Sandstone	plug						$0.5x10^{-4}$	$1.69x10^{-4}$	BIA, 1976
Siltstone	plug						0.005-	0.016-	BLM, 1975
range	plug						$0.6x10^{-6}$	$2.2x10^{-6}$	BIA, 1976
Stray Coal	plug		-	-	0.21	2.27	0.57	1.87	
Rosebud-McKay Coal									
Rosebud (5)	pump		7.6	25	32	343	4.2	13.78	Van Voast,1977
McKay (4)	pump		3.0	10	1.2	13	0.5	1.5	Van Voast1977
	pump		10.7	35	0.4	4.6	0.04	0.13	BIA, 1976
	pump				0.01-0.56	0.13-6.01	0.01-2.3	0.04-7.7	BIA, 1976
Siltstone, Shale									
Stray Coal Interburden	plug		-	-	-	-	0.11-0.17	0.38-0.56	BIA, 1976
Sandstone	pump		15.2	50			0.171	0.562	BIA, 1976
Robinson Coal	pump				0.03-0.9	0.3-9.4	0.01-1.4	0.04-4.7	BIA, 1976
Sub Robinson									
Shale,Siltstone	plug		-	-	-	-	$2.7x10^{-4}$-0.1	$9x10^{-4}$-0.4	BIA, 1976
Sandstone Lower Sandstone	pump		18.2-27	60-90	0.3-1.1	3-12	0.01-2.3	0.04-7.5	BIA, 1976

TABLE B-7. SUMMARY OF LITERATURE SEARCH FOR HYDRAULIC PROPERTIES OF MINE SPOIL

Site of Test	Type of Test	Storage Coefficient	Transmissivity m^2/d	Transmissivity ft^2/d	Hydraulic Conductivity m/d	Hydraulic Conductivity ft/d	Reference
HIDDEN VALLEY MINE, WYO.	pump	0.17	137	1477	18.3	60.1	1
	infiltration				2.7	8.8	
	laboratory				0.4	1.3	
BIGHORN MINE, WYO.	pump	0.23	2.1	23	0.16	0.53	1
	infiltration		0.2	2.1	3.4	7.0	
	laboratory				0.4	1.3	
ROSEBUD MINE, MT.	infiltration				1.2	4	1
	laboratory				0.5	1.5	
DECKER MINE, MT.	infiltration				0.2	0.6	1
	laboratory				0.04	0.12	
WYODAK MINE, WYO.	infiltration				1.1	3.75	1
	laboratory				0.6	2.0	
BELLE AYR MINE, WYO.	infiltration				0.5	1.72	1
ROSEBUD MINE, MT.	pump		1.5	16	0.7	2.3	2
	range of pump tests				0.01 2.0	0.07 7	3
DECKER MINE, MT.	infiltration spoil 1 month old				0.8	2.8	4
	spoil 24 months old				0.07	0.24	

References:
1. Rahn, 1976
2. Van Voast and Hedges, 1977
3. Van Voast, 1973
4. Farmer and Richardson, 1976

TABLE C-1. SATURATION EXTRACT DATA

a) LOGGING CREEK PRIORITY STUDY AREA

NCRP Well	Interval Sampled (ft below land surface)*	pH	mmhos/cm Cond.	SAR	% Sat	Meq/l					ug/l B	ug/l NO_3-N
						Ca	Mg	Na	HCO_3	SO_4		
NCRP 27	0-20'	8.7	3.0	27.2	116	0.8	1.3	28.0	3.2	25.0	0.04	<1
	21-40'	8.9	2.1	37.2	113	0.3	0.3	20.0	7.0	13.6	0.03	<1
	41-60'	9.1	2.6	53.7	111	0.3	0.2	26.8	7.4	17.5	0.02	<1
	61-80'	7.4	11.4	23.1	58.3	22.0	18.3	104	8.1	120	1.20	<1
	81-100'	8.7	4.3	33.5	64.3	1.4	1.6	41.1	7.1	34.6	0.10	2
	101-120'	8.4	6.8	45.0	88.2	1.8	2.8	68.1	9.4	60.2	0.06	16
	121-140'	8.4	8.2	42.4	80.3	2.4	5.3	82.9	13.2	71.1	0.11	22
	141-160'	8.4	9.4	47.9	84.8	2.5	5.7	96.8	11.3	86.5	0.05	19
	161-180'	8.2	8.7	47.0	102	2.4	5.3	92.0	16.0	79.1	0.05	7
	181-200'	8.2	7.0	36.6	94.8	2.5	5.3	72.0	18.1	60.2	0.06	<1
NCRP 30	0-20'	8.2	5.0	6.0	38.8	15.0	24.2	26.6	1.6	52.0	0.37	58
	21-40'	8.4	0.7	3.5	49.4	1.0	1.8	4.2	2.8	3.1	0.06	8
	41-60'	9.0	0.8	3.2	32.8	0.9	2.7	4.2	3.7	3.5	0.21	<1
	61-80'	9.1	0.8	2.6	29.2	1.4	2.7	3.7	2.4	4.9	0.34	<1
	84-91'	8.9	0.8	2.2	21.7	2.5	2.8	3.5	3.1	4.6	0.51	<1
NCRP 32	0-20'	9.8	2.4	2.9	28.5	13.7	2.2	8.3	1.8	17.9	0.09	2
	21-40'	8.8	3.2	4.9	30.6	16.6	3.6	15.5	1.6	32.8	1.34	2
	42-60'	8.6	4.8	5.0	34.7	18.8	24.2	23.0	2.3	58.0	2.50	<1
	81-100'	8.6	4.6	4.8	28.1	26.4	8.6	20.2	1.5	54.2	2.03	4
	101-120'	8.5	3.6	2.6	28.4	18.2	15.1	10.8	1.1	40.6	2.24	<1
NCRP 29A	0-20'	8.2	7.5	10.9	21.4	15.6	29.8	52.1	2.5	84.1	0.20	20
	21-40'	8.5	1.7	4.7	31.4	3.4	5.3	9.8	2.4	14.3	0.14	1
	41-60'	7.9	1.6	2.1	46.8	4.2	9.9	5.5	5.4	13.0	0.07	<1
	61-80'	8.0	2.8	4.6	35.3	4.0	15.5	14.5	8.1	26.0	0.07	<1
	81-100'	8.0	3.3	5.6	30.9	5.3	15.5	18.0	6.3	32.8	0.09	<1
	101-120'	7.8	3.6	6.6	33.6	6.6	13.5	21.0	5.7	34.6	0.10	<1
	121-140'	8.1	4.3	13.6	25.0	3.0	8.1	31.8	11.0	32.0	0.08	<1
	141-160'	8.3	5.3	20.0	35.3	2.7	2.3	46.9	12.2	39.3	0.09	14
	161-180'	8.2	5.1	24.4	43.5	1.8	6.2	49.0	12.9	41.1	0.08	<1
NCRP 8A	0-20'	8.2	6.0	4.0	33.1	24.5	39.6	22.6	1.5	70.1	0.35	<1
	0-60'	8.3	6.0	12.7	35.7	8.6	19.1	47.3	1.9	65.2	0.41	<1
	61-100'	8.6	2.4	13.1	49.0	1.5	2.5	18.5	4.4	17.0	0.06	2
	101-140'	8.5	2.4	13.8	43.9	1.5	2.4	19.5	5.7	17.0	0.08	<1
NCRP 21	0-30'	8.4	3.4	6.8	47.2	5.2	10.6	19.0	2.7	30.5	0.48	10
	31-58'	8.1	2.2	5.1	21.2	7.2	7.9	10.5	5.1	19.6	0.85	<1
	65-90'	6.8	6.7	0.8	52.3	28.3	78.0	5.9	4.4	92.9	2.38	<1

*To convert to meters, divide by 3.28

b) BUFFALO JUMP PRIORITY STUDY AREA

(b) BUFFALO JUMP PRIORITY STUDY AREA

NCRP Well	Interval Sampled (ft below land surface)*	pH	mmhos/cm Cond.	SAR	% Sat	Meq/1 Ca	Mg	Na	HCO_3	SO_4	ug/1 B	ug/1 NO_3-N
NCRP 22	0-20'	7.3	7.9	2.9	59.3	16.2	94.5	21.6	6.7	106	0.12	88
	21-40'	7.8	4.4	5.6	36.6	13.3	24.4	24.5	2.1	52.8	0.15	30
	41-60'	8.4	3.2	24.6	50.7	1.4	1.6	29.7	4.8	27.6	0.03	1
	61-80'	8.8	2.4	21.8	87.1	0.8	0.7	19.5	4.5	17.1	0.03	1
	81-100'	9.0	2.1	22.4	76.2	0.6	0.6	17.6	5.2	13.5	0.03	<1
	101-120'	8.8	2.9	18.1	59.1	1.6	1.5	22.7	3.6	21.6	0.05	1
	121-140'	8.6	3.0	12.9	38.6	2.2	4.8	24.2	4.1	24.7	0.03	<1
	141-160'	8.8	1.8	14.4	36.2	0.8	1.4	15.2	6.2	10.4	0.03	<1
	161-180'	8.6	2.1	14.2	39.2	1.1	1.6	16.7	6.7	13.3	0.02	<1
	181-200'	8.5	2.6	11.4	43.8	2.0	3.9	19.5	4.3	19.8	0.02	<1
	201-226'	8.1	3.5	7.8	42.9	6.4	9.3	21.7	4.1	33.0	0.06	<1
NCRP 19	0-20'	8.5	0.6	1.4	38.8	1.7	2.1	2.0	2.4	3.6	0.36	<1
	21-40'	8.8	0.9	7.9	29.6	0.8	0.6	6.4	3.0	5.7	1.03	<1
	41-60'	8.7	0.3	2.4	33.0	0.6	0.5	1.7	1.6	1.6	0.24	<1
	61-80'	8.5	0.6	1.2	31.7	2.0	2.0	1.6	1.4	4.7	0.36	<1
NCRP 4	141-170'	7.0	6.4	13.8	64.9	14.6	15.6	53.8	5.4	67.4	0.21	<1
	171-200'	7.8	4.1	14.4	67.6	4.2	6.9	34.0	4.2	33.3	0.04	24
	201-250'	7.8	3.2	4.8	58.8	9.5	13.2	16.3	2.9	33.3	0.13	<1
	251-270'	7.8	2.1	2.8	57.1	7.4	10.2	8.3	3.3	20.9	0.19	<1
	270-300'	7.9	2.6	4.4	46.0	4.8	11.6	12.8	5.0	23.8	0.07	<1
	301-332'	7.9	2.1	2.7	43.3	4.2	12.6	7.9	6.2	18.6	0.07	<1
NCRP 26	0-20'	8.4	5.1	11.6	72.6	3.6	19.5	39.4	2.6	50.2	0.03	18
	21-40'	8.5	2.5	10.4	65.7	2.1	4.1	18.5	5.2	18.8	0.03	<1
	41-60'	8.7	1.8	19.5	79.1	0.6	0.7	16.2	8.8	8.6	0.02	<1
	61-80'	7.4	9.5	18.0	54.1	16.2	13.1	69.0	6.7	84.7	0.23	<1
	81-100'	8.8	1.1	15.2	72.0	0.4	0.3	9.2	5.1	5.0	0.04	2
	101-120'	8.8	1.0	13.8	72.3	0.4	0.3	8.6	4.1	4.1	0.03	17
	121-140'	8.5	2.5	16.4	62.9	1.4	1.6	20.0	5.7	15.3	0.06	30
	141-160'	8.4	3.9	7.5	33.8	1.3	1.5	19.7	1.7	41.8	0.13	5
	161-180'	8.5	3.9	8.8	33.8	8.8	10.0	23.1	2.6	37.5	0.29	24
	181-190'	7.8	7.0	15.1	42.3	17.1	12.0	57.7	3.1	77.6	1.06	92
NCRP 24	0-20'	8.3	2.0	6.0	53.1	2.6	6.1	12.4	1.5	16.4	0.04	<1
	21-40'	8.3	1.0	4.2	30.7	1.6	2.3	5.9	1.9	5.6	0.07	<1
	41-60'	8.8	0.5	2.1	33.7	1.0	1.6	2.3	2.7	1.3	0.13	<1
	61-80'	9.1	0.6	2.5	28.0	1.0	1.4	2.7	2.8	2.4	0.21	<1
	81-100'	8.8	0.5	3.0	43.3	0.4	0.9	2.4	1.7	2.6	0.12	<1
	101-120'	9.4	0.3	2.2	28.3	0.6	0.5	1.6	1.5	1.4	0.13	<1
	121-140'	9.2	0.4	2.6	25.0	0.8	0.8	2.3	2.0	2.2	0.34	<1
	141-160'	8.8	0.4	2.2	30.2	0.8	0.9	2.0	1.7	1.7	0.15	<1
	161-175'	7.8	3.9	1.8	54.0	20.7	27.9	9.1	1.5	45.4	0.32	<1

*To convert to meters, divide by 3.28

C) INDIAN COULEE PRIORITY STUDY AREA

NCRP Well	Interval Sampled (ft below land surface)*	pH	mmhos/cm Cond.	SAR	% sat	Ca	Mg	Meq/l Na	HCO$_3$	SO$_4$	ug/l B	ug/l NO$_3$-N
NCRP 36A	21-40'	8.5	2.1	0.8	30.2	11.4	12.6	2.7	1.7	22.1	0.09	<1
	41-55'	8.3	2.7	0.7	41.8	13.0	19.9	2.7	2.1	31.8	0.08	<1
	64-75'	6.9	6.4	0.4	46.1	24.4	69.1	3.0	3.0	79.4	1.81	<1
NCRP 40A	0-26'	8.7	0.3	0.4	30.6	1.1	1.0	0.4	2.1	0.4	0.03	<1
	31-50'	8.3	1.4	1.0	42.5	5.4	7.4	2.4	1.7	12.1	0.16	<1
	51-70'	8.3	1.6	2.0	41.7	4.4	8.5	5.0	1.6	14.3	0.06	<1
	71-87'	7.5	3.2	3.6	45.2	14.4	11.9	13.1	4.5	34.1	0.55	<1
NCRP 18	0-46'	6.4	5.0	3.5	42.5	26.2	27.4	18.0	9.8	51.1	1.08	8

*To convert to meters, divide by 3.28

TABLE C-2. LEACHING TESTS - NCRP - DISTILLED WATER

LEACHING TESTS - NORTHERN CHEYENNE RESEARCH PROJECT - DISTILLED WATER

Conducted by Dr. D.A. McWhorter, Colorado State University

The leaching data contained in the following tables was obtained with distilled water input. Indicated pickup of dissolved solids and leaching characteristics should simulate that to be anticipated by precipitation infiltrating the various spoil materials.

DATA TABLE #1

Sample Nos. NCRP - 30 & 32 (clinker) - Site #2

Wt of sample before drying = 222.50 gm (includes tare = 31.62 gm)
Wt of sample after drying = 211.80 gm (includes tare = 31.62 gm)

Loss = 10.70 gm

Wt of sample = 222.50 - 31.62 = 190.88 gm

Moisture content = 10.70/190.88 = 0.056

Wt of sample in leaching column = 1850 gm
Dry wt in leaching column = 1850 (1-0.056) = 1746 gm
Vol. of material in teaching column = (34 cm)x $(6.9)^2 \pi/4$ = 1270 ml

Dry Bulk density = 1746 bm/1270 = 1.37 gm/ml
Porosity = 1 - 1.37/2.65 = 0.48
Pore Volume = (0.48) (1270) = 610 ml

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist. ohm - cm	EC mmhos/cm	Temp. oc	ph	Hyd. cond. cm/sec
115	0.188	180	5.56	23.0		
320	0.525	230	4.35	22.5	8.4	1.16×10^{-4}
400	0.656	320	3.13	23.0	8.4	3.80×10^{-4}
470	0.770	370	2.70	23.0	8.5	2.84×10^{-4}
830	1.361	880	1.14	23.0		2.42×10^{-4}
1150	1.885	1250	0.80	23.0		2.42×10^{-4}
1690	2.770	1900	0.53	23.0		
1950	3.197	1950	0.51	23.0		2.45×10^{-4}
2490	4.082	2350	0.43	23.0		
4290	7.033	2800	0.36	23.0		

Hydraulic gradient during test = $\frac{OH}{L} = \frac{22cm}{34cm} = \underline{0.647}$

Average Hydraulic Conductivity = 2.5×10^{-4} cm/sec

SAMPLE NOS. NCRP - 21

Wt of sample before drying = 263.40 gm (includes tare = 27.30gm)

Wt of sample after drying = 258.05 gm (includes tare = 27.30gm)

Loss = 24.0 gm

Wt of sample = 263.40 - 2730 = 236.10 gm

Moisture Content = 5.35/236.10 = 0.0227

Wt of sample in leaching column = 1400 gm
Dry wt in leaching column = 1400 (1-0.0227) = 1368 gm
Vol. of material in leaching column = $(30)\ (6.9)^2 \frac{\pi}{4} = 1122$ ml

Dry Bulk Density = 1368/1122 = 1.22 gm/ml
Porosity = 1 - 1.22/2.65 = 0.54
Pore Volume = (0.54) (1122) = 606 ml

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist. ohm - cm	EC mmhos/cm	Temp. oc	ph
30	0.050	100	10.0	23.5	6.8
180	0.297	140	7.14	23.0	
450	0.743	250	4.00	23.5	6.7
570	0.941	340	2.94	22.5	6.8
600	0.990	430	2.33	23.0	
1840	3.036	1310	0.76	23.0	7.0
3070	5.066	1870	0.53	23.0	
4090	6.749	2700	0.37	23.0	
5370	8.861	4300	0.23	23.0	

Samples No. 4 & 22

Wt of sample before drying = 265.00 gm (includes 26.85 gm tare)
Wt of sample after drying = 242.50 gm (includes 26.85 gm tare)

Loss = 22.50 gm

Wt of sample = 265.00 - 26.85 = 238.15 gm

Moisture content = 22.5/238.15 = 0.0945

Wt of sample in leaching column = 1800 gm
Dry wt in leaching column = 1800 (1-0.0945) = 1630 gm
Vol. of material in column = $(34)\ (6.9)^2\ /4$ = 1271 ml

Dry Bulk density = 1630/1271 = 1.28
Porosity = 1 - 1.28/2.65 = 0.516
Pore Volume = (0.516) (1271) = 656 ml

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist. ohm - cm	EC mmhos/cm	ph
45	0.069	78	12.82	
310	0.473	130	7.69	
440	0.671	420	2.38	
536	0.817	560	1.79	8.5
632	0.963	760	1.32	8.85

Samples No. 36A & 40A

Wt of sample before drying = 266.50 gm (includes 26.43 gm tare)
Wt of sample after drying = 256.05 gm (includes 26.43 tare)

Loss = 10.45 gm

Wt of sample = 266.50 gm - 26.43 = 240.07 gm

Moisture content = (10.45) / 240.07 = 0.0435

Wt of sample in leaching column = 2100 gm
Dry wt in leaching column = 2100 (1 - 0.0435) = 2009 gm
Vol. of material in column = $34\ (6.9)^2 \pi\, 14$ = 1271 ml

Dry Bulk density = 2009/1271 = 1.58
Porosity = 1 - 1.58/2.65 = 0.40
Pore Volume = (0.40) (1271) = 513 ml

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist ohm/cm	EC mmhos/cm	Temp. oC	ph
70	0.137	140	7.13	22.5	7.7
110	0.214	154	6.49	23.0	7.5
130	0.253	160	6.25	23.0	7.6
170	0.331	181	5.52	23.0	
290	0.565	210	4.76	23.0	
390	0.760	235	4.26	23.0	
500	0.975	255	3.92	23.0	
620	1.209	285	3.51	23.0	
1120	2.183	550	1.82	23.0	
1540	3.002	2600	0.38	23.0	
2150	4.191	2900	0.34	23.0	8.1

LEACHING TESTS - NORTHERN CHEYENNE RESEARCH PROJECT WELL-WATER

Conducted by Dr. D. A. Mc Whorter, Colorado State University

The leaching data contained in the following tables was obtained using water from wells located in corresponding areas.

Sample Nos. 30 and 32 (water from 29 A)

Dry wt. of sample in column = 1850 (1-0.056) = 1746 gm

Volume = (34.2) $(6.9)^2 \pi/4$ = 1279 ml

Dry Bulk Density = 1746/1279 = 1.365

Porosity = 1 - 1.365/2.65 = 0.48

Pore Volume = (1279) (0.48) = 614 ml

EC of Input at time of experiment = 1.65 mmhos/cm @23°c

PH of Input at time of experiment = 7.7

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore-Vols.	Specific Resist. ohm/cm	EC mmhos/cm	Temp oc	ph
40	0.065	170	5.88	23.0	8.0
55	0.090	150	6.67	23	7.6
100	0.163	150	6.67	22.5	7.7
295	0.480	185	5.40	22.5	7.7
335	0.546	185	5.40	22.5	7.8
380	0.619	195	5.13	22.5	7.8
405	0.660	200	5.00	22.5	7.7
445	0.725	300	3.33	22.5	7.8
610	0.994	400	2.50	22.5	7.9
720	1.173	460	2.17	22.5	7.7

Sample Nos. 50, 52 & 57 (water from 53)

Dry wt. of sample in column = 1778 (1-0.080) = 1636 gm

Vol. of sample = 36.5 $(6.9)^2 \pi/4$ = 1365 ml

Dry Bulk Density = 1636/1365 = 1.20

Porosity = 1 - 1.2/2.65 = 0.55

Pore Volume = (0.55) (1365) = 751 ml

EC of Input at time of experiment = 2.33 mmhos/cm@23°

PH of Input at time of experiment = 7.5

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist. ohm-cm	EC mmhos/cm	Temp. oc	ph
50	0.067	150	6.67	23	7.3
155	0.206	170	5.88	23	7.8
280	0.373	180	5.56	23	7.7
440	0.586	220	4.55	23	7.8
885	1.178	280	3.57	23	7.8
950	1.265	295	3.39	21.5	7.8
1100	1.465	310	3.23	22	7.8
1195	1.591	310	3.23	22	7.6

Sample Nos. NCRP 24 & 26

Wt of Sample before drying = 254.50 (includes 31.30 gm tare)
Wt of sample after drying = 230.50 (includes 31.30 gm tare)

Loss = 24.0 gm

Wt of sample = 254.50 - 31.30 = 223.20 gm

Moisture content = 24/223.20 = 0.1075

Wt of sample in leaching column = 1600 gm
Dry wt in leaching column = 1600 (1.000 - 0.1075) = 1428 gm
Volume of material in column = (31) $(6.9)^2 \pi 14$ = 1159 ml

Dry Bulk density = 1428/1159 = 1.23
Porosity = 1 - 1.23/2.65 = 0.54
Pore Volume = (0.54) (1159) = 621 ml

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist. ohm - cm	EC mmhos/cm	Temp. oC	ph
45	0.072	395	2.53	23.0	8.3
130	0.209	430	2.33		
290	0.467	520	1.92		
600	0.966	970	1.03	22.5	8.4
850	1.369	1600	0.62	23.0	8.6
1190	1.916	2500	0.40	23.0	
2360	3.800	2950	0.34	23.0	8.8
3300	5.314	3500	0.29	23.0	
3990	6.425	3800	0.26	23.0	
4590	7.391	3800	0.26	23.0	

Sample Nos. 24 & 26 (water from 22)

Dry wt. of sample in Column = 1635 (1 - .1075) = 1476 gm

Volume = (33) $(6.9)^2 \pi/4$ = 1234 ml

Dry Bulk Density = 1476/1234 = 1.20

Porosity = 1 - 1.20/2.65 = 0.55

Pore Volume = (1234) (0.55) = 675 ml

EC of Input at time of experiment = 2.50 mmhos/cm @23°c

PH of Input at time of experiment = 7.9

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore-Vols.	Specific Resist ohm /cm	EC mmhos/cm	Temp oc	ph
40	0.059	310	3.23	23	8.2
190	0.282	310	3.23	23	8.2
280	0.415	295	3.39	23	8.2
500	0.741	295	3.39	23	8.2
660	0.978	290	3.45	23	8.3
820	1.215	295	3.39	22.5	8.3
1320	1.956	370	2.70	21.5	8.4
1420	2.104	380	2.63	22	8.4
1540	2.281	380	2.63	22	8.4
2570	3.807	380	2.63	22.5	8.4
2710	4.015	390	2.56	22	8.4
3195	4.733	400	2.50	21.5	8.4
3380	5.007	390	2.56	22	8.4

Sample Nos. 36A & 40A (water from 18)

Dry wt. of sample in column = 1546 (1 - 0.0435) = 1479 gm

Vol. of sample = (28.5) $(6.9)^2 \pi/4$ = 1066 gm

Dry Bulk Density = 1479/1066 = 1.388 gm

Porosity = 1 - 1.388/2.65 = 0.476

Pore Volume = (0.476) (1066) = 508 ml

EC of Input at time of experiment = 3.94 mmhos/cm @23°c

PH of Input at time of experiment = 7.7

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore Vols.	Specific Resist ohm/cm	EC mmhos/cm	Temp oc	ph
40	0.079	137	7.30	23	7.5
82	0.162	145	6.90	23	7.6
200	0.396	152	6.58	23	7.8
510	0.010	185	5.40	21.5	7.7
560	0.109	175	5.71	22	7.9
610	0.208	180	5.56	22	7.9
650	1.287	175	5.71	22.5	7.9
745	1.475	210	4.76	22	7.9
945	1.871	210	4.76	21.5	8.0
1075	2.129	220	4.55	22	8.0

Sample Nos. 4 & 22 (water from 22)

Dry wt. of sample in column = 1116 (1- 0.0945) = 1011 gm

Vol. of sample = 22 $(6.9)^2$ /4 = 823 ml

Dry Bulk Density = 1011/823 = 1.228

Porosity = 1 - 1.228/2.65 = 0.536

Pore Volume = (0.536) (823) = 442 ml

EC of Input at time of experiment = 2.5 mmhos/cm @23°c

PH of Input at time of experiment = 7.9

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore-Vols.	Specific Resist. ohm/cm	EC mmhos/cm	Temp. oc	ph
26		260	3.85	23	8.4
40		230	4.35	22.5	8.6
82		190	5.26	22	8.5
95		182	5.50	22	8.5
105		190	5.26	22.5	8.5
111		178	5.62	22	8.5
131		155	6.45	21.5	8.4
235		170	5.88	22	8.0
299		175	5.71	22	8.2
423		210	4.76	22	8.2

Sample No. 21 (water from 21)

Dry wt. of sample in Column = 1715 (1-0.0227) = 1676 gm

Volume = (35) $(6.9)^2\pi/4$ = 1309 gm

Dry Bulk Density = 1676/1309 = 1.28

Porosity = 1 - 1.28/2.65 = 0.51

Pore Volume = (1309) (0.51) = 667 ml

EC of Input at time of experiment = 3.12 mmhos/cm @23°c

PH of Input at time of experiment = 7.9

Cumul. Vol. of Effluent ml	Cumul. Vol. of Effluent Pore-Vols.	Specific Resist. ohm/cm	EC mmhos/cm	Temp oc	ph
40	0.060	100	10.0	23	6.5
62	0.093	99	10.1	23	6.8
195	0.292	140	7.14	22.5	7.1
785	1.177	195	5.13	21.5	6.9
895	1.342	220	4.55	22	7.3
1075	1.612	240	4.17	22	7.3
1195	1.792	250	4.00	22.5	7.3
1290	1.934	275	3.64	22	7.6
1650	2.474	275	3.64	22	7.6
1920	2.879	295	3.39	22	7.6